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Reducing Climate Change Related Fugitive Greenhouse Gas Emissions from Operational Longwall Coal Mines

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Abstract

The aim of this research is to quantify and validate a method which can significantly reduce fugitive greenhouse gas emissions from collieries in Australia, both cost-effectively and safely. Methane (CH_4) is controlled in collieries currently only for safety, statutory compliance or for capture and use reasons. But today, there is pressure on collieries to reduce not only mining costs but their greenhouse gas emissions. It is known that 65% of greenhouse gas (GHG) emissions associated with collieries come from fugitive ventilation air methane (VAM). The oxidising machinery to mitigate these fugitive emissions is expensive, has safety concerns and is not widely used at present for these reasons. But widespread concern over GHG emissions means that it is desirable to lower VAM emissions now. One safe, low-cost and non-gas drainage solution explored herein to reduce emissions, is a method to prevent some CH_4 from entering the mine airstream and becoming VAM in the first place. This emissions reduction method underwent a 12-month trial in a colliery in the Hunter Valley using six different quantified and costed non-gas drainage measures. All relevant data was retained, and with the mine's permission has been processed and published here as a part of this research. A reduction in fugitive emissions of 95,398 t/CO_2-e below that projected for the subsequent 12 months was quantified, at a mitigation cost of A$1.08 t/$CO_2$-e. The level of mitigation achieved, represents approximately 20% of the mine's VAM emissions. This research has also further tested the method used in the Hunter Valley trial, by visiting two other large collieries in Queensland, and assessing the two most successful mitigation measures from the Hunter Valley trial (roadway sealing and pressure balancing of sealed panels) against operational conditions at these collieries by ventilation modelling, using their measured gas, airflow and seal pressure data.

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Papers published, conferences attended in relation to this work;

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- Holmes, R. I. (2016b). Reducing ventilation air methane emissions cost-effectively and safely. *Energy & Environment, 27*(5), 566-585.
- Holmes, R. I. (2016c). Conference speech; Cutting GHG emissions cost-effectively in Australia. FedUni conference for HDR research works, 21st June 2016.
- Holmes, R. I. & Tuck, M. (2016d). Mitigating fugitive GHG emissions safely and cost effectively. *Conference paper presented at the International Symposium on Green Mining 2016 at the University of Wollongong, December 1st. 2016.*
- Holmes, R. I. (2017a). Mitigating ventilation air methane cost-effectively from a colliery in Australia. Conference paper and presentation. *16th North American Mine Ventilation Symposium, Colorado, USA; 19th June 2017.*
- Holmes, R. (2017b) Calculating surface temperatures on planetary bodies with atmospheres >10 kPa. Conference paper and presentation. *HDR research conference at Federation University, 27th July 2017.*

Statement of authorship and originality

Except where explicit reference is made in the text of the thesis, this thesis contains no material published elsewhere or extracted in whole or in part from a thesis by which I have qualified for or been awarded another degree or diploma. No other person's work has been relied upon or used without due acknowledgment in the main text and bibliography of the thesis. No editorial assistance has been received in the production of the thesis without due acknowledgement. Except where duly referred to, the thesis does not include material with copyright provisions or requiring copyright approvals.

Signed;  Robert Ian Homes, date; 22/09/2017

List of abbreviations

APS	American Physical Society
AR4	Fourth Assessment Report of the IPCC (2007)
AR5	Fifth Assessment Report of the IPCC (2014)
BOM	Australia's Bureau of Meteorology
CCN's	Cloud Condensation Nuclei
CEATR	Central England Air Temperature Record
CERES	Clouds and the Earth's Radiant Energy System
CERN	Conseil Européen pour la Recherche Nucléaire
CFRR	Catalytic Flow Reversal Reactors
CLOUD	Cosmics Leaving Outdoor Droplets (experiment)
CH_4	Methane
CME	Coronal Mass Ejection (from the Sun)
CMIP-5	The most recent version of the climate models
CMR	CSIR Lean Burn Turbine and Catalytic Combustor
CO_2	Carbon Dioxide
COP	Conference of Parties - meetings to discuss climate
CPRS	Carbon Pollution Reduction Scheme
CRF	Cosmic Ray Flux
CSG	Coal Seam Gas (is often mostly methane)
CSIRO	Commonwealth Scientific and Industrial Research Organisation
c/t	Cut-through (a short mine roadway)
CWP	Current Warm Period
DA	Dark Ages
DEV	Development (part of a colliery)
DLR	Downwelling Longwave Radiation
ECS	Equilibrium Climate Sensitivity
EERS	Emissions & Energy Reporting System
EGGWH	Enhanced Greenhouse Gas Warming Hypothesis
EPA	Environmental Protection Authority (USA)
ERF	Emissions Reduction Fund
GCM	Global Circulation Models
GCR	Galactic Cosmic Rays

GHE	Greenhouse Effect (said to total 33°C)
GHG	Greenhouse Gases
GISS	Goddard Institute for Space Studies – part of NASA
Goaf or Gob	Area which has been undermined by a longwall panel
GWP	Global Warming Potential
Gy	Billion Years
Gya	Billion Years Ago
hdg	Heading (a long mine roadway)
INQUA	International Union for Quaternary Research
IPCC	Intergovernmental Panel on Climate Change
ky	Thousand Years
kya	Thousand Years Ago
LIA	Little Ice Age
LOD	Length of Day
LW	Longwall in a coal mine, where production occurs
MET	The United Kingdom's Meteorological Office
MW	Megawatt (1,000 Kilowatts)
MWP	Medieval Warm Period
My	Million Years
Mya	Million Years Ago
NASA	National Aeronautics and Space Administration
NGER	National Greenhouse Energy Reporting
NGO	Non-Governmental Organisation
NH	Northern Hemisphere
NIPCC	Non-governmental International Panel on Climate Change
NTE	Near-surface Thermal Enhancement
NUG	Newlands Underground coal mine
OC	Open cut coal mine
OLR	Outgoing Longwave Radiation
Pa	Pascals of pressure
RCP8.5, 6.0, 4.5 and 2.6	Representative Concentration Pathways in W/m^2
RET	Renewable Energy Target
RWP	Roman Warm Period

S-B	Stefan-Boltzmann Law for black bodies
SC	Solar Cycles
SCC	Social cost of Carbon
SN	Sunspot Number
TCR	Transient Climate Response
TFRR	Thermal Flow Reversal Reactors
TOA	Top Of Atmosphere (refers to solar insolation flux)
TSI	Total Solar Irradiance
UG	Underground mine
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change
VAM	Ventilation air methane
WGI, WGII and WGIII	Working Group I, II and III of the IPCC reports

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Introduction

Chapter one will explore the need for this research into cost-effective VAM mitigation and cover the main research questions. Chapter two will examine the existing literature in relation to methane in coal mines, why it poses a safety risk and its control. Chapter three will cover the science of global warming and climate change, which is the hot issue of the day, garnering the attention the United Nations, academia and of all governments – even down to the local level in western democracies. The main focus has been on the unregulated emission into the atmosphere of two man-made greenhouse gases (henceforth GHG), carbon dioxide (CO_2) and methane (CH_4). Coal, which when mined and used, emits both of these gases in copious amounts; Australia is perhaps the biggest coal exporter globally, and coal is the country's second largest export earner after iron ore. Considerable concern exists among a section of the community in western countries, when these gases are emitted into the atmosphere. And where government or company action to prevent the emission of these GHG is seen by this section to be inadequate, various climate activist or non-governmental organisations (NGO's) are highly visible. Given this situation, the pressure on coal mines has increased; is there real justification for this? In short, how solid is the scientific evidence behind the man-made global warming alarm? Are there real scientific reasons to worry about the present level of man-made emissions of these gases? Are the massive costs in terms of capital, resources and human lives to restrict emissions of these two gases really necessary?

Gaining accurate answers, based in solid scientific evidence gleaned by the use of the proven scientific method, to these questions is fundamental, considering that the stakes according to some, may well extend as high as the very survival of our species. As will be discussed, the main documents relating to possible future climate change that are relied on by governments, academia and the media, are the ones issued by the UN's IPCC. It will be argued that relying on IPCC reports alone is totally inadequate, given the stakes. This forms the top secondary research question, and it will be answered in chapter three, where the science of climate change, as found in the literature, will be carefully and critically examined. In particular, the emphasis will be on what the IPCC reports have missed from the literature; - the critical aspects of the field of climate change that comprises the so-called 'missing science' (Plimer, 2009). As might be expected when political bodies such as the UN and the IPCC are involved, politics plays a pivotal role, and this aspect will be explored in chapter four.

The concern over GHG emissions has adversely affected coal mining in western democracies; although emphasis has generally been on CO_2 emissions from coal-fired power stations, awareness is rising that a significant portion of coal-related emissions are to do with the act of mining itself. These mainly take the form of VAM fugitive emissions. Reducing VAM fugitive emissions from operational underground coal mines is a vexatious issue when using standard oxidation methodologies because of the difficulty of safely treating the low percentage of methane which is contained in the high mine airflows. A master's thesis was completed in 2009, part of which was on estimating VAM gas emissions by using three different measurement methods in order to validate their accuracy (Holmes, R. 2009). Later, preparatory work for this PhD thesis on cost-effective VAM mitigation was undertaken. This involved works aimed at reducing VAM emissions in a Hunter Valley colliery; it is a method of mitigation involving six different non-gas drainage measures. Notes and raw data were retained for later quantification. The extent of the VAM mitigation achieved by each measure, and the cost of implementation was then quantified. The results of this 12-month trial are detailed in chapter five, and were also published (R. Holmes, 2016a) (R. I. Holmes, 2016b). The mitigation achieved was 95,398 t/CO_2-e over a projected 12-month period, at a cost of A$1.08/t/$CO_2$-e.

To validate or invalidate the postulate that the quantified VAM mitigation of 95,398 t/CO_2-e/yr which was achieved in the Hunter Valley colliery, could be transferrable to other, similar longwall collieries in Australia, two more Australian longwall collieries were selected for data collection and ventilation modelling. The two measures from the Hunter Valley trial which gave the most mitigation at a low cost were selected and the two collieries (henceforth Mine A and Mine B) were visited in August 2016. Gas concentrations, seal pressures and air-flow measurements for the modelling process were taken during the underground visits from previously identified target areas. Ventilation modelling of CH_4 flows for the two best mitigation measures were then undertaken for each mine, to assess whether the postulate that the method, and specifically its two best measures, could be successfully transferred to other collieries.

The results of the modelling are presented in chapter six; quantities and costs are then compared side-by-side to the actual 12-month trial results from the Hunter Valley. In collieries, the safety impact of any works is always vitally important, and these impacts were also identified and quantified, and are presented in chapter seven. Financial and public relations aspects are also important in mining and are presented in chapter seven.

**Note; a small but significant error has been found in both of the Holmes 2016 papers since publication; the GWP of* CH_4 *should have read 25 and not 21, because this figure was changed by the IPCC in the AR4 published in 2007. The updated figure for the GWP of* CH_4 *has been used throughout this paper, and has resulted in greater* CO_2*-e VAM mitigation, and in slightly lower abatement costs per tonne than was originally reported for the NSW trial in those papers.*

1 Chapter 1: The context of this research

1.1 Why does it need research?

There exists a paucity of research material in the literature that focusses on reducing the fugitive GHG CH_4 from entering the mine airstream, using non-gas drainage methods in underground longwall coal mines. The main aim of this work is to quantify and cost alternative ways to reduce the environmental footprint of a colliery by mitigating its VAM fugitive GHG emissions safely, quickly and without a large capital investment. The method will involve six measures, which collectively will be shown to reduce fugitive VAM emissions by approximately 20% in a 12-month trial at a NSW colliery.

1.1.1 The main aims and benefits of this type of mitigation

- To reduce the release of the known GHG Methane into the atmosphere.
- To reduce their possible associated high carbon price costs for that release; (the 2012 carbon price was set at A$575.00 per tonne for fugitive CH_4) (Lodhia, 2011).
- To reduce the risk of an unforeseen spontaneous combustion event, associated with multi-seam or single-seam long-wall mining, which may lead to a mine fire or explosion, leading to personal injury to mineworkers and/or the temporary or permanent closure of the mine.
- Prevention of vehicle or machinery ‘trips’ (stoppages) due to gas levels exceeding the machinery trip level.
- Prevention of gas levels exceeding statutory requirements in normally accessible areas of the mine, resulting in those areas becoming designated by a mine official as ‘inaccessible’.
- Prevention of normally machine accessible areas from being inaccessible to machinery during diurnal or other pressure falls or lows.
- Prevention of costly long-wall stoppages or panel evacuations due to gas levels exceeding statutory limits.
- Prevention or a reduction in the requirement to report gas trips or evacuations to the inspector of mines, due to those gas trips or evacuations reducing in number or not happening at all.
- To improve mine safety by helping to prevent the undesirable development of large volumes of explosive mixtures of gases in new goaf areas and the prevention of large volumes of explosive mixtures of gases in old goaf areas.
- To raise carbon credits for the financial benefit of the colliery.
- To raise the environmental capital of the colliery in the eyes of the public.

1.2 What is the primary research question?

The first part of this research involved conducting a non-gas-drainage VAM mitigation trial at an operating NSW colliery, and then using this raw data to calculate firstly whether the trial was successful and cost-effective; and if so, which two of the six measures reduced the most fugitive VAM gas emissions. The second part of this research will take the non-gas drainage mitigation of fugitive VAM under operational mining conditions further. This involved visiting two other VAM-affected Australian collieries, and the collection of gas, airflow, pressure and other data from these collieries, which will be called Mine A and Mine B. This data enabled the modelling of the two most successful measures in the NSW trial to take place which were; a roadway seal-up and the pressure balancing of a panel, to be performed. This modelling is intended to validate or to invalidate the possibility that this mitigation method – and in particular these two measures, are transferable to other collieries in Australia. VAM mitigation estimates, along with costing estimates, allow a direct comparison to be made with NSW trial data. Supplementary benefits to the mine, such as safety and financial aspects are also estimated.

Two candidate measures arise from the trial as detailed in chapter five and are;

Candidate measure 2; The seal-up of an unnecessary mine roadway and
Candidate measure 5; The pressure balancing of a sealed panel

These measures, implemented in the Hunter Valley trial and detailed in chapter five, mitigated 67,100 t/CO_2-e and 16,070 t/CO_2-e of VAM fugitive emissions respectively (Table 5.10) over a projected 12-month period, both safely and at a relatively low cost.

1.3 Primary research question;

Can these specific two mitigation measures be as successful at cutting VAM fugitive emissions at other, large Australian collieries?

This primary research question is addressed in chapter six.

1.4 Secondary research questions;

i. ***How solid is the scientific evidence behind the desire to reduce emissions of GHG?***
ii. ***What are the likely safety benefits to a colliery of implementing these mitigation measures?***
iii. ***What are the possible benefits with regard to the generation of carbon credits for a colliery?***

1.5 Importance of this work;

- Because VAM gas represents a significant 1.5% of all global anthropogenic GHG emissions, and more than 6% of all anthropogenic emissions in Australia

(Zhongqing et al., 2010) (Su, Beath, Guo, & Mallett, 2005) if anthropogenic emissions are to be reduced by government policy, it should be a target for emission cuts.

- Methane is a high global warming potential (GWP) gas, and the UNFCCC originally assigned it a GWP of 21 (John Theodore Houghton, 1996), this was later increased to 25 (Solomon, 2007). Effectively, it means that 1 tonne of emitted methane (CH_4) has the same greenhouse effect (GHE) as 25 tonnes of carbon dioxide (CO_2) emissions.
- The Australian government has a current target emissions reduction of 5% below 2000 levels to be achieved by 2020. This target is a bipartisan target. Any cuts should logically be made in a cost-effective way and this work demonstrates that reducing fugitive emissions from underground coal mines by using the correct method can be achieved safely and at a relatively very low cost.
- The aim of this method is to reduce the quantity of methane gas reporting to the mine fans in the first place; in other words, preventing some methane from entering the mine air and becoming VAM.The need for mitigation such as the VAM works detailed herein has a strong dependent relationship to a wider field of knowledge, namely; climate change science. The current state of which is examined in some detail in chapter three.
- Globally, a new international agreement was agreed to in Paris at the United Nations framework convention on climate change (UNFCCC) conference of parties (COP21) meeting in December 2015. For Australia, this entails extending the 2020 restrictions on its GHG emissions, to 2030. Australia has committed to the further target of a 26-28% reduction below 2005 emission levels by 2030 (Papon & Smith). However, the Paris agreement is now in jeopardy, with one of the main participants, the USA, walking out of the agreement (ABC news, 2017). But the USA now represents less than 18% of anthropogenic global emissions, and this percentage is falling rapidly, so the Paris agreement may still live on.
- Bearing the reality of these new emissions targets in mind, having proven methods readily available to reduce emissions quickly, cheaply and safely is prudent.

1.6 This project will add to the knowledge base;

No quantified and costed non-gas drainage papers could be found in the worldwide literature which demonstrate a quantified and costed reduction of VAM creation specifically for environmental reasons in an operating colliery; even though these residual fugitive GHG emissions represent most of a typical colliery's emissions (Zhongqing et al., 2010) (Su et al., 2005). Many papers were found which indirectly reduce this source of GHG emissions; this method often involved coal seam gas (CSG) drainage using long bore-holes through the coal seams (Jura, Skiba, & Wierzbinski, 2014). In some cases, injected nitrogen assists gas production (Packham, Cinar, & Moreby, 2011); however, the aim of all the gas drainage was either about safety, statutory limit compliance, ventilation assistance

(Zuber, Boyer, Charles, & Delozier, 1999) or was production-oriented (Guo, Todhunter, Qu, & Qin, 2015) rather than principally aimed at residual and fugitive GHG mitigation.

It is expected that this work, and its associated publications will add to the knowledge base by answering the following questions;

- how to target and reduce significantly the 'low-hanging fruit' of VAM gas?
- which of the six quantified measures were the most successful?
- which of the six costed measures are the most cost-effective?
- which additional measures might also be successful at cutting VAM emissions?
- is the method/measures transferrable to other, similar collieries in Australia?
- what is the mitigation cost per tonne of CO_2-e of each measure, compared to mitigation costs in other areas of the economy?
- how does the implementation of these measures affect mine productivity?
- how does the implementation of these measures affect mine safety?
- how will the cost of these measures be funded?
- what contribution could this method make to Australia's overall emissions target?
- how solid is the science behind the desire to reduce GHG emissions?
- how does the changing international scene of climate action affect Australian mitigation efforts?

1.7 Justification for the significance of the work;

Some attention has been paid in the literature to addressing the greatest source of underground coal mine GHG emissions; that of VAM gas. Issues with VAM will grow in the future because more and more long-wall coal mines in Australia (and around the world) will increasingly find it necessary, to mine lower and therefore gassier seams.

Although there are concerns about the GHG emissions which fossil fuels like coal produces, the low price of electricity production available by using thermal coal and the requirement of metallurgical coal for steel-making means that coal is still set to remain a very important energy source globally for decades to come. However, international forces are at play which demand that any emissions which can be reduced or mitigated are so reduced, and it is important for Australia that this is done at the lowest cost. As this research will show, it is possible to reduce these residual fugitive emissions of VAM substantially, safely, and at a much lower cost per tonne than mitigation works in many other areas of the economy.

1.8 Methodological framework;

To assess the performance of the above method in mitigating VAM during actual mining conditions, both during the NSW trial, and during the modelling of Mine A and Mine B, the following data has been collected, collated and presented;

- real-time and tube-bundle data
- the main fans and secondary fan data
- ventilation survey data
- gas drainage data
- back-road bleed information
- seal changes and seal monitoring arrangements
- gas monitoring arrangements
- pressure survey data
- modelling information and predictions
- statutory gas limits in legislation
- gas survey data
- remediation plan
- new seal design and performance
- data on gas explosability concentrations
- mine plans and drawings

1.9 Justification of approach;

The research problem can be defined as to how can fugitive GHG emissions be reduced while still managing problems such as high gas makes, explosion and spontaneous combustion risks in an underground longwall coal mine? The chosen research method; that of collecting, collating and presenting all relevant data taken from operating mines, while working under the stipulated conditions is the best way of answering the research question in a scientific way. Science is about numbers and the collated data is basically a numerical representation of the method and the individual measures that can be used to reduce residual fugitive VAM emissions.

1.9.1 Mechanised mining is an integral part of a modern society

At a time when some are calling for mining to be ‘stopped’, it need hardly be said that to sustain this civilisation, mechanised mining is necessary, just as there is a need for mechanised farming. Without a technically advanced and highly organised mining sector, there simply wouldn’t be any modern society or technology to speak of. Humanity would quickly collapse back hundreds of years to a new dark age, where life for the vast majority would revert to being crude and short. The planet's present standard of living - and its current population of 7.5 billion would be totally insupportable, and a sudden and precipitous fall in both of these would be certain if mechanised mining were to be dramatically slowed or brought to a stop. This grim, but all too real scenario, simply cannot be allowed to happen.

2 Chapter 2: VAM literature review

2.1 Overview of the relevant literature

A literature review on VAM gas mitigation is outlined in this chapter, as is the nature of fugitive emissions and the properties of CH_4. Globally, most anthropogenic CH_4 sources originate in agriculture (Karakurt, Aydin, & Aydiner, 2012) (Yusuf, Noor, Abba, Hassan, & Din, 2012) oil and gas are 18% of sources, VAM from coal mines represents only 6% - even landfills and wastewater produce more fugitive CH_4. Nevertheless, VAM emissions are significant in terms of Australia's emissions, representing ~40Mt (Authority, 2014) (Figure 2.7) out of the total of ~600Mt, which is about 7%. Few papers could be found in the worldwide literature which singularly address how to reduce VAM creation specifically for environmental reasons in an operating colliery, even though these remaining fugitive emissions represent most of a typical colliery's GHG emissions (Zhongqing et al., 2010) (Su et al., 2005). Those which were found, are almost all relating to large - scale VAM treatment plants, of the type which are attached to the main mine exits or main mine fans (S. F. Wood, DF Joseph, S Dawson, A Harris, AT) (2006) and mitigate through oxidation. The well-known issues of cost and safety with these plants are discussed later in this chapter.

2.1.1 Push factors; why deeper and more multi seam collieries are likely

Up until the present time underground longwall coal mines in Australia have generally targeted a single coal seam, and so have not been exposed to the problems uniquely associated with multi seam longwall coal mining. Historically, approvals for new collieries were generally not difficult to obtain. However, in recent years, the regulations covering the establishment of a new coal mine and in particular stricter environmental and planning requirements associated with opening a new or a 'greenfield' colliery have grown exponentially. New coal mine applications can now be tied up for many years in the planning and approvals stages; some even eventually fail to obtain approval at all. These growing delays in a potential mine's start-up have increased the costs enormously, and commensurately reduced the incentive for investors to commence a new coal mine. In a related move, coal seam gas mining has been put on a moratorium in both NSW and Victoria, creating gas shortages in those states. Community and activist resistance is now a factor, and is strongly against any new coal mines; recent targets have been Whitehaven in the Hunter Valley and Carmichael in the Galilee Basin (Colagiuri, Cochrane, & Girgis,

2012) (Grech, Pressey, & Day, 2015) (Denniss, 2015) (Gleeson, 2016). In NSW, the continuing actions against Whitehaven mine has now reached a level that NSW premier Mike Baird was forced to pass tougher laws to deter activists (Tasker, 2015). This situation has resulted in a push factor which effectively encourages existing collieries to mine lower seams on their existing leases, over time this actually increases GHG emission, because lower seams are generally gassier.

2.1.2 Sustainability in coal mining

There has also been a push in recent years for sustainability in resource use, presumably meaning that any resource should be maximised in recovery, and recycling practices should be pursued for used, recyclable materials. These two push factors have led to a re-thinking of resource recovery on existing colliery leases. The costs of developing two new slopes down to access a lower, minable seam are high; but this needs to be assessed in the light of the now much higher costs and the probable approvals delays associated with moving to a new site. Of course, the lower seams need to be comprehensively assessed for depth and coal quality before the decision to mine is taken. A ventilation assessment also needs to be undertaken, which takes into consideration the specific ventilation issues unique to multi seam coal mining. Issues such as the extra gas make associated with a deeper seam, how the undermined goaf and its gases are to be managed to prevent volumes of flammable gas from forming, the prevention of irrespirable atmospheres in working areas, prevention and early detection of any spontaneous combustion in rider seams or explosive mixture events when goafs combine. The methods to be used to minimise fugitive GHG emissions in the form of VAM gas should also be outlined. One recent gas drainage innovation which can assist in this is directional drilling (Jura et al., 2014). Another is better reservoir modelling for targeting gas drainage (Karacan, 2007).

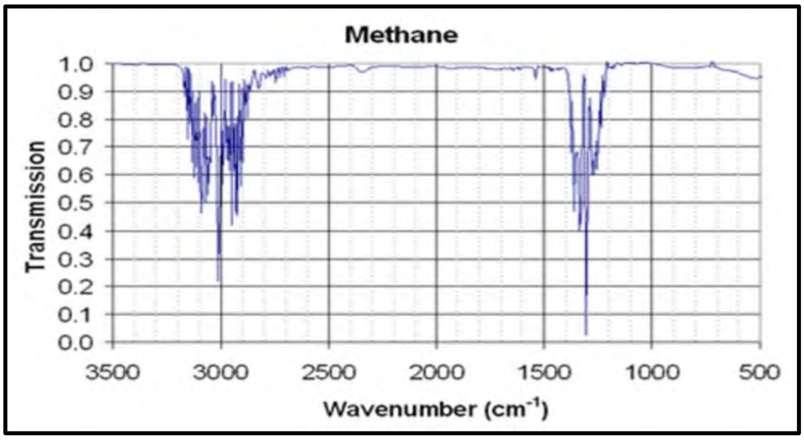


Figure 2.1 Absorption bands are 3.3 and 7.7 microns (Nielsen & Nielsen, 1935)

2.1.1 Where does methane fit in as a GHG?

When VAM is spoken of, this is about methane gas. Although methane (CH_4) is a strong GHG, there is very little of it in the atmosphere, in fact less than 2ppm; for comparison, CO_2, itself a trace gas, is around 400ppm. And in terms of its greenhouse effect (GHE), CH_4 only affects out-going infrared radiation in a small part of the electromagnetic spectrum (Figure 2.1).

The Earth emits radiation mainly in the 4 – 100 µm range, in the infrared band of the spectrum, and CH_4 has two thin absorption bands (Nielsen & Nielsen, 1935) at 3.3 and 7.7µm (wavenumbers 3020cm^{-1} and 1300cm^{-1}); these are the wavelengths where CH_4 could absorb and re-emit outgoing infra-red radiation. Of the total outgoing radiation which is absorbed and re-released by atmospheric greenhouses gases, which constitute the greenhouse effect, CH_4 is presently only involved in perhaps at most 1% of the activity (Schmidt, Ruedy, Miller, & Lacis, 2010). The actual change in the greenhouse effect of doubling atmospheric CH_4 is different to that of CO_2; CH_4 being linear and CO_2 being logarithmic (Saeki, Mizuno, & Kondo, 1976) i.e. a doubling of CH_4 theoretically leads to a doubling of the effect on temperatures, but a doubling of CO_2 does not lead to a doubling of the effect on temperatures. If the total greenhouse effect is indeed 33°C, as is claimed, then logic therefore dictates that the total effect of CH_4 is minimal at just 0.3°C, and so a doubling of the atmospheric concentration might lead to a 0.3°C rise in global surface temperatures. Doubling CO_2 is different and does not lead to a doubling of its existing greenhouse effect, instead, each doubling is said to lead to a rise in global temperatures of perhaps 1.2°C (J. Houghton, 1992) before feedbacks – so a quadrupling then leads to a rise of 2.4°C before feedbacks. A result of the logarithmic nature of the greenhouse effect of CO_2 is that half of the pre-industrial greenhouse effect from CO_2 actually comes from the initial 20ppm, with the other half coming from the subsequent 260ppm. Different researchers have published different climate sensitivities before feedbacks. The doubling from the pre-industrial level of 280ppm to 560ppm, would cause (before feedbacks); 1.46°C (Lindzen, Charnock, Shine, & Kandel, 1995); 1.2°C (J. T. Houghton, 1985); 0.64°C (Lindzen, Chou, & Hou, 2001). Although the more widely accepted figure is Houghton's 1.2°C. As will be seen in chapter three, uncertainties abound in all areas of climate science.

If 33°C is taken as being the correct figure for the total greenhouse effect caused by greenhouse gases, and if the 20% portion being attributed to CO_2 as being correct, (Schmidt et al., 2010) then 6.6°C will be arrived at for a rough approximation of the current greenhouse effect of CO_2.These figures lead directly to the 0.64°C from Lindzen's later work for a doubling before feedbacks, which follows from the diminishing response (Figure 3.40) caused by the logarithmic absorption curve of CO_2. Lindzen has stated that even if all the warming seen in the 20th century was anthropogenic, then this still indicates to him that the climate sensitivity is low (Lindzen & Choi, 2009). This point of view comes straight out of the temperature data, given that the changes since 1750 in major GHG already amounts to an increase of 85% in CO_2-e equivalent terms (Authority, 2014).

2.2 Fugitive emissions from underground coal

2.2.1 What are fugitive GHG?

Fugitive GHG in the context of underground coal mining are those which escape to the atmosphere during the process of mining coal. Typical of these – and by far the greater portion in terms of its GHE – is the coal seam gas (CSG) methane (CH_4). CH_4 has a GWP of 25, and its chemical sign is CH_4, indicating that it is made up of one atom of carbon and four atoms of hydrogen. Other fugitive GHG are CO_2 made of one carbon atom and two oxygen atoms. These molecular arrangements (which include two different atoms), mean that these gases are *dipoles* and can absorb and re-emit infra-red radiation of certain wavelengths (Scheutz, Kjeldsen, & Gentil, 2009). Coal mine fugitive emissions (primarily methane) currently make up ~40Mt or ~6% of Australia's total GHG emissions. (Authority, 2014) (Figure 2.8). These are the residual VAM emissions; they comprise of the methane which is left in the coal seams after any gas drainage which has taken place, and which enter the mine air during mining and are then expelled through the mine fans into the atmosphere. It is the residual VAM fugitive emissions which are targeted by this research.

2.3 Why should coal mines reduce GHG?

Why should coal mines take action to reduce GHG? This research is geared towards testing a cost-effective method of reducing residual VAM fugitive emissions. But also important to assess is the likelihood of any Australian government mandates on GHG emissions, and on Australia's participation with, and entering into international treaties, which will result in regulations on coal mines to minimise their emissions. There remains also a possibility that a future Australian government might take unilateral action with the same regulatory result for coal mines. This has already happened when a carbon price was put on fugitive coal mine emissions, (based on the NGERs emission estimates) by a previous government (Lodhia, 2011); the carbon price was in place during the period 1 July, 2012 to 30 June, 2014. There are also reasons other than mandates that coal mines might want to reduce their VAM emissions beyond simply those of safety and statutory requirements. These include; compliance with 'green tape' regulations which constitute a part of a greenfield mining permit, the need to increase machinery access to returns during diurnal lows, to raise carbon credits or to achieve gains in community and public relations. Internationally, the pressure is already on developed countries to cut their GHG emissions. There is considerable concern at two UN agencies, the UNFCCC and the IPCC, among most western governments, many climate scientists, academia and most sections of the western media. NGO's like Getup, 350.org and Greenpeace and some sections of the community are also very concerned that anthropogenic emissions of GHG, if continued or increased, will or have already adversely affected the climate system. How strong the scientific evidence is that supports these concerns has been carefully researched and is presented in detail, in chapter three.

2.3.1 Why are fugitive emissions considered to be a problem?

Fugitive CH_4 emissions from coal mines are considered to be a problem because CH_4 is a strong GHG and in theory, should contribute to global warming; CH_4 has been allocated a GWP of 25 (Solomon, 2007). According to the latest report (the AR5) by the Intergovernmental Panel on Climate Change (IPCC) (Team, Pachauri, & Meyer, 2014) anthropogenic GHG emissions are escalating fast (Figure 2.2) and this rise is the biggest contributing factor to the current period of global warming, which can cause climate change. Climate change which happens relatively suddenly can adversely affect species (Crowley & North, 1988). Perhaps a greater threat for humanity is to the coastal cities from a sea level rise (Rahmstorf, 2007). A warming climate would melt more land ice causing a eustatic sea level rise; and a warming climate would also cause some thermal expansion of the oceans, leading to thermosteric sea level rise. Since the start of industrialisation in 1750, there has been a measured 0.8°C global temperature rise, and global circulation models project about 3°C more in coming centuries if the growth in emissions of GHG such as CO_2 and CH_4 continues on a business as usual path (Team et al., 2014).

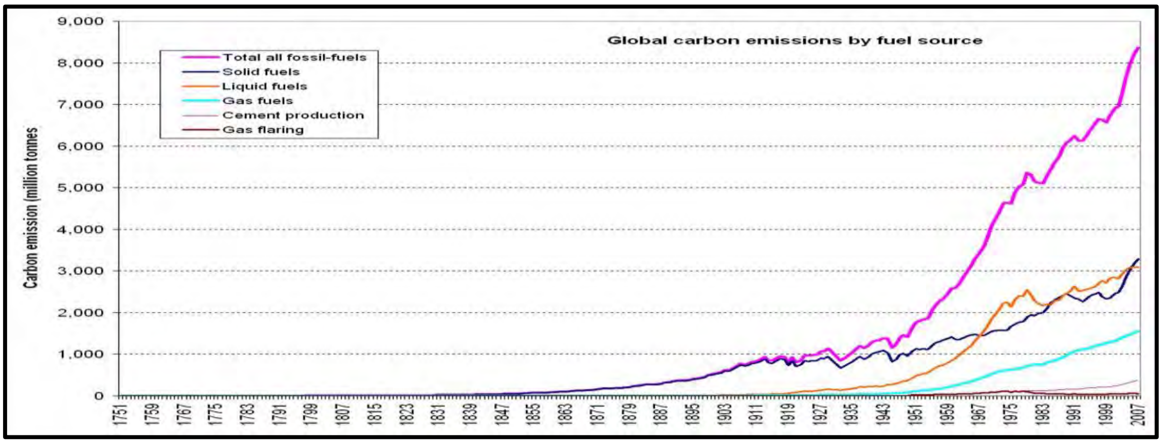


Figure 2.2 Human carbon emissions by fuel source 1751-2007 mt/yr (Team et al., 2014)

Table 2.1 GWP of some GHG (Solomon, 2007)

Carbon dioxide	CO_2	1
Methane	CH_4	24
Nitrous oxide	N_2O	298
Sulphur Hexafluoride	SF6	22,800

Coal mining companies must comply with legislation in this area. Concern is rising amongst the public in the western economies about environmental issues and has been for several decades; coal mining companies must make sure that the public's perception is that they are 'doing their share' to address this identified challenge This now forms part of the 'social licence to operate' which is now very real in western countries such as Australia. Given the patchy environmental record of mining historically, and how the industry's performance in this area was seen in the past, there is a need to publicise any environmental efforts made, and in the current climate there is also a need to be seen to be trying to reduce anthropogenic GHG emissions. Coal mining is Australia's second largest export industry, is a large employer and provides the fuel for most of the country's electrical power generation; however, it is also a large emitter of GHG. Determining GWP: it is calculated from the radiative forcing capacity (RF) (Table 2.1) that is, how much energy is adsorbed by the gas for a unit of time-area. RF is calculated by the formula;

$$\mathrm{RF} = \sum_{n=1}^{100} Absi * Fi/(pathlength * density)$$

Where; i = 10 inverse centimetres, Absi = the integrated infrared absorbance of the sample in the interval and Fi = the RF for the interval (Allen et al., 2014).The high GWP of CH_4 at 25 x CO_2 (Myhre, Boucher, Bréon, Forster, & Shindell, 2015) combined with the low concentration of VAM which is typically 0.3% of mine air flow, mean that VAM emissions pose a difficult problem for engineers to deal with once they reach the mine fans.

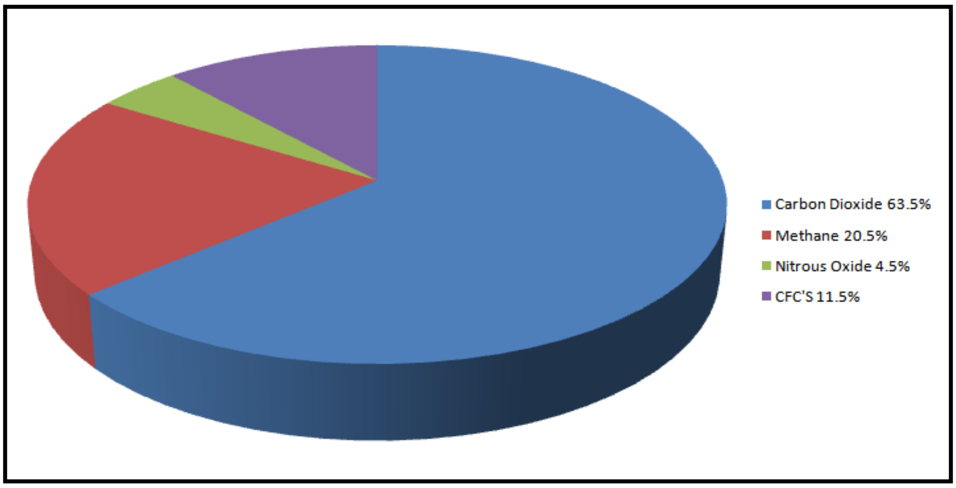


Figure 2.3 Global man-made GHG emissions, 20.5% is methane (Allen et al., 2014)

The VAM concentration varies rapidly 0.1% – 0.8% in the high airflow mine air which compounds the problem and means that it is very difficult to remove (Karakurt, Aydin, & Aydiner, 2011). Per the IPCC, CH_4 is 20.5% of all man-made GHG emissions (Figure 2.3); most, (51%) of this CH_4 is agricultural emissions (Karakurt et al., 2012) but a significant 7% (of the 20.5% that is CH_4) is VAM fugitive emissions. This means that VAM gas comprises a significant 1.5% of global anthropogenic GHG emissions. Globally, this is currently ~630Mt CO_2-e, and ~40Mt CO_2-e for Australia (Figure 2.4).

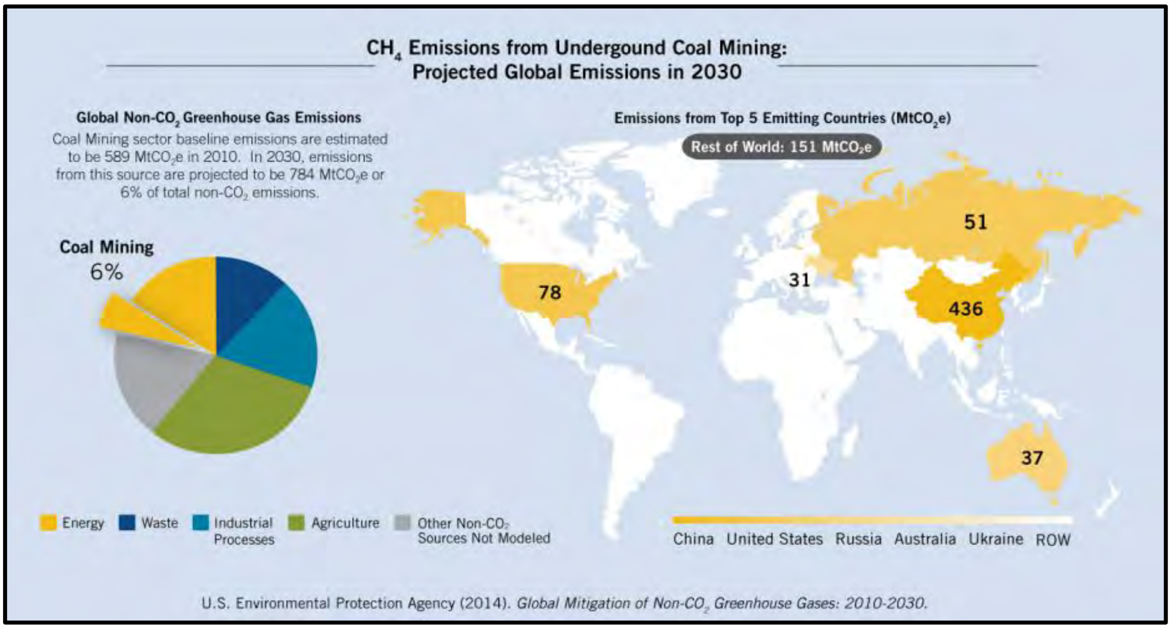


Figure 2.4 CH_4 emissions from coal mines in Mt/CO_2-e 2010 (U.S. EPA, 2017)

At present, the technology to mitigate VAM cost-effectively, efficiently and safely is a work in progress (Baris, 2013). However, there is concern at present over VAM fugitive GHG emissions, and that these need to be reduced.

Australia's climate change authority (Authority, 2014) outlines the possible range of fugitive emissions from coal mines in Australia to 2030. Fugitive emissions from coal mines currently (2017) represent ~40Mt CO_2-e which is a significant 6.5% of Australia's total anthropogenic GHG emissions. An increase in VAM gas emissions is anticipated on a business as usual scenario, up to 70Mt CO_2-e, because of projected increases in coal exports and the mining of lower, gassier seams. Around 2022 the use of VAM plants is expected to significantly reduce this source of emissions. However, there are large uncertainties in the projected figures (Figure 2.5).

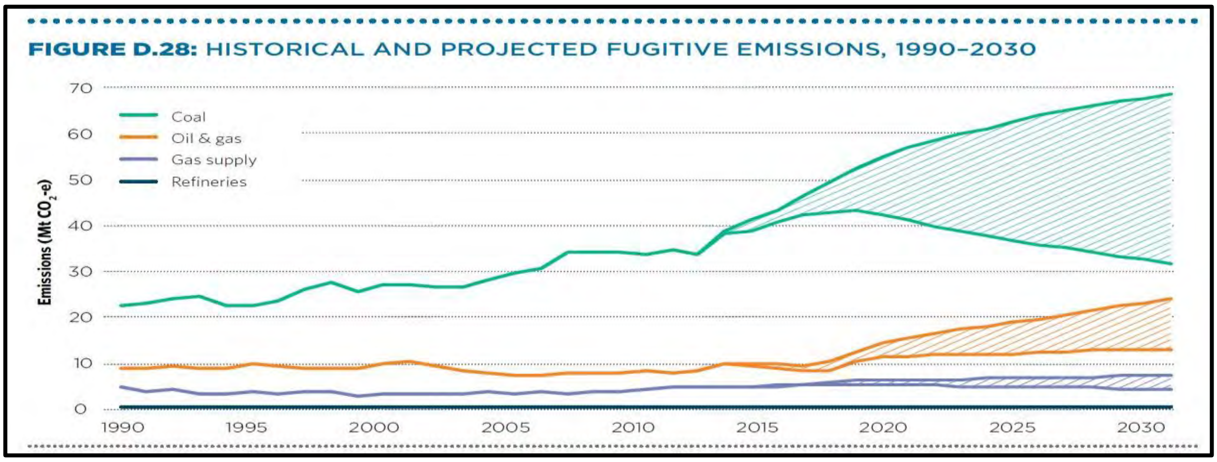


Figure 2.5 Projected fugitive emissions from coal mines (Authority, 2014).

2.3.2 Methane in collieries

CH_4 is stored in coal by a process called adsorption in large quantities, and this also relates to depth (Figure 2.6). The amount of CH_4 contained in a tonne of coal ranges from 2 m^3 to 30 m^3; the CH_4 is adsorbed into the micro-porous matrix of the coal by intra-particle diffusion, (Zhao, Jiang, & Chu, 2012) and pressure keeps it in place.

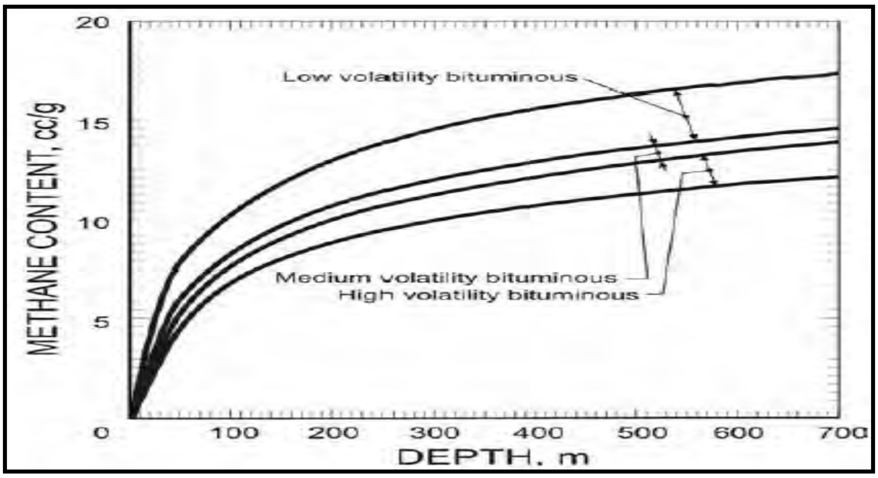


Figure 2.6 The CSG CH_4 content in coal mainly relates to depth

Collieries in Australia are seven times more emissions-intensive than open cut mines. They totalled just 19 per cent of Australian coal production in 2010–11 but 62 per cent of all the fugitive GHG emissions from coal (Authority, 2014). This is because Coal Seam Gas (CSG) content is related to depth (Figure 2.6). CSG is generally mostly CH_4 (Sly, Bryant, Cox, & Anderson, 1993) and is liberated from pores in the coal when the water pressure holding it in place is lowered during either the act of pre-mining gas drainage, or during the mining itself. The CH_4 released during mining either enters the ventilation airstream becoming VAM gas or rises through its buoyancy to occupy the spaces between the broken rock and coal in or above the seam being mined, in what is known as the 'goaf'; it either remains there or is drawn off by a surface gas drainage plant. CH_4 taken by a gas drainage plant is high in concentration, and can often be used to run gas generators, treated for home use or can be destroyed by flaring in the following chemical reaction;

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$

CH_4 destroyed by flaring does reduce emissions as opposed to simply venting to atmosphere. This reduction is calculated in the following way. The molecular mass of 1kg of CH_4 is 16 atomic mass units, three-quarters of which is carbon. There is therefore 0.75kg of carbon per kg in the CH_4. In CO_2, each carbon atom combines with two oxygen atoms and the molecular mass is 44 atomic mass units. The mass of CO_2 given off will be 44/12 times the mass of the carbon, which is 3/4 the mass of the CH_4. So, burning 1kg of CH_4 releases;

$$44/12 \times 3/4 \times 1kg = 2.75kg \text{ of } CO_2$$

When 1 kg of CH_4 is burnt in air, the combustion process forms 2.75 kg of CO_2, (Hinde et al., 2016) which has a GWP of 1. Given that CH_4's GWP is 25, effectively, for every 1 kg of CH_4 that is fully burnt, emissions are reduced by;

$$25 - 2.75 = 22.25 \text{ kg } CO_2\text{-e.}$$

2.3.2.1 Why CSG content is so high

When the pressure which keeps the CH_4 in place reduces, it diffuses into the cleats of the coal. A study (Saghafi, Williams, & Lama) (1997) has shown that the CH_4 released from a mine is generally four to seven times that which is contained in the coal seam being mined. This general rule was independently confirmed during measurements of gas makes vs coal seam content at Newlands coal mine in Queensland (Holmes, R. 2009). The act of longwall mining relaxes strata up to 170m above and up to 60m below the seam, so most VAM can originate outside the seam being mined, from both above and below (Kissell, 2006). Applying this knowledge means that gas emission rates from a worked seam can be better predicted, enabling the required ventilation flows to be calculated (Noack, 1998).

Table 2.2 Emissions and energy (Holmes, R. 2009)

Fuel	**CSG CH_4**	**Black Coal**	**Biodiesel**
Energy Content	0.0377GJ/ m^3	27 GJ per t	34.6 GJ m^3
Emissions CO_2	0.051 t/GJ	2.38 t/t	0 t/ m^3
Emissions CH_4 (CO_2-e)	0.0002 t/GJ	0.001 t/t	0.020 t/ m^3
Emissions N_2O (CO_2-e)	0.00003 t/GJ	0.005 t/t	0.007 t/ m^3
Total CO_2-e emissions/GJ	0.051 t/GJ	0.088 t/GJ	0.00078 t/GJ

Table 2.2 details the energy content and emissions of the waste CSG CH_4 compared to coal and biodiesel. Note that CH_4 produces only 58% of the CO_2 emissions that black coal does, for the same amount of electrical power generated. CH_4 gas is therefore seen not only as a reliable source of power generation, but as a 'cleaner' energy source than coal. Fugitive emissions of CH_4 remain a concern; however, note that CH_4 does break down naturally into relatively harmless CO_2 in the atmosphere in 9-15 years (Wigley, 1998). Its atmospheric concentration is very low and appears to be stabilising at less than 2 parts per million (Figure 2.7).

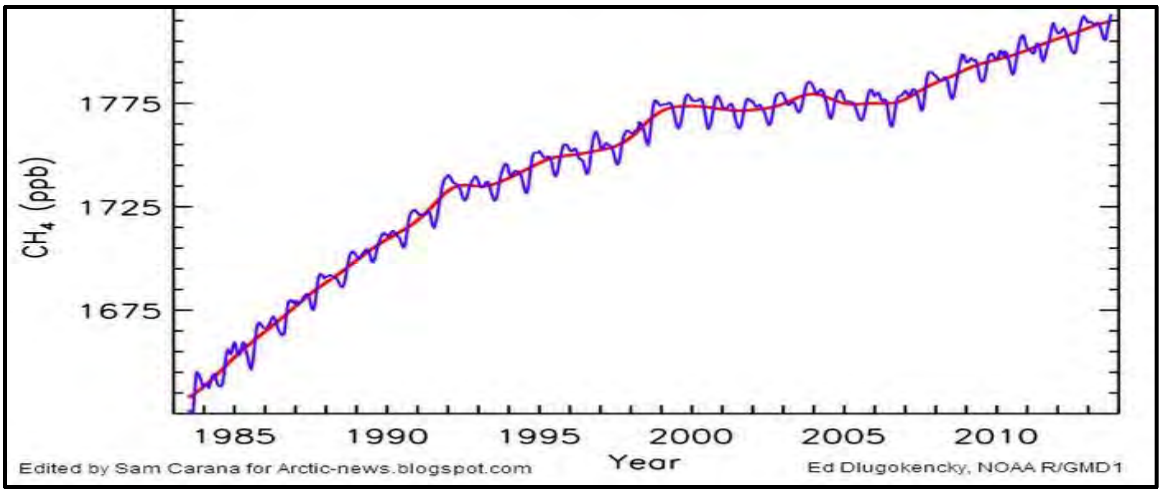


Figure 2.7 Atmospheric CH_4 breaks down to CO_2 in 9-15 years (Wigley, 1998)

Historically, coal mines have seen the CSG CH_4 as more of a problem than as a potential source of revenue; but the fact is that CH_4 is a source of energy, the contained energy of the VAM released into the mine air is typically about 1% of that contained in the mined coal itself (Holmes, R. 2009).

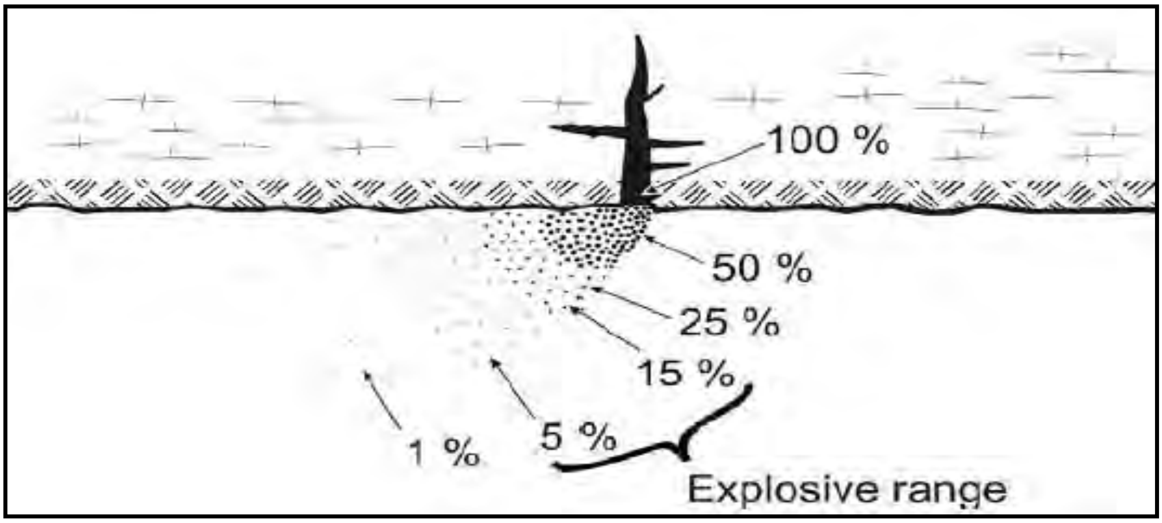


Figure 2.8 CH_4 emitted from a coal seam into mine air becomes VAM (McPherson, 2009)

2.3.3 The environment and fugitive methane emissions

The main way of dealing with the CH_4 emitted into the mine air is by dilution, using large volume air flows; the VAM is then expelled from the mine and into the atmosphere. Environmental awareness related to CH_4 as a GHG has only become apparent in the more recent years. CH_4's contribution as a GHG to global warming concerns, and the changing GHG legislation related to this, has focussed many coal mine management's attention on this CSG. Disposing of unwanted CH_4 gas for safety reasons has always involved large costs in terms of gas drainage, monitoring, safety precautions and extra ventilation flows;

there are also extra costs associated with utilizing the gas for power generation, although this could be recovered from sales of the energy.

2.3.3.1 The dilution of emitted CH_4 creates VAM

CH_4 emissions from the coal seam into accessible roadways are generally made safe by rapid dilution using large volumes of fast-flowing air (Figure 2.8). CH_4 is a problem in collieries because it forms an explosive mixture between 5% and 15% when in air (M. McPherson, 2009). It is also a strong GHG when released into the environment. The former problem has been recognised since coal mining first began, and strict controls are in place to ensure that CH_4 concentrations in accessible, working areas of the mine do not exceed statutory limits, which are typically 1% for machinery and 2% in person-accessible areas (CMHSR, NSW & QLD).

Figure 2.9 Moranbah North CH_4 gas power station

2.3.4 Gas drainage

When CH_4 concentrations might cause an outburst event or are too high to be dealt with efficiently and safely by the ventilation system alone, gas drainage is employed. Typically, the CH_4 is drained to the surface from a goaf during production or from in-seam drainage through a gas well prior to mining. Although sometimes, underground gas drainage is the only alternative (Miles & Scott, 2014). A typical flow rate from a gas well would be 1,000 l/s and is often high in concentration at about 90% CH_4. A 1MW gas generator requires 75 l/s of 100% CH_4 for operation, and so with this typical flow rate, a bank of 12 or more 1MW gas generators could be run to generate a useful amount of electrical power, as at Moranbah North, in QLD or Integra in NSW. (Figure 2.9)

Figure 2.10 Oakey Creek waste mine gas flaring plant

The alternative to power generation is usually to destroy the CH_4 by flaring, as is done at Oaky creek in QLD and Ashton in NSW (Figure 2.10), which dramatically reduces the GHE of the emissions. Obviously, it is better to produce electricity from the waste gas if it is possible. One difficulty here is that mine operators see themselves as coal miners, not as power generators or gas suppliers. One way this may be overcome is to have a small additional department in technical services to deal with gas mitigation issues, so that the extra work does not fall on the ventilation officer or the gas drainage engineer. Often though, the drained gas is sold or on-supplied at a low price to an outside company to deal with. Note that if a new supply of CH_4 becomes available through the actions of a NGERS-reporting mine, or CH_4 is otherwise prevented from becoming fugitive emissions, funds may well be available under the government's direct-action auction system, which aims to cut GHG emissions, in the form of carbon credits (Regulator, 2012).

2.3.5 Overview; historical CH_4 control in collieries

Historically and currently, once the CH_4 is at safe levels or within compliance limits, no further attempt is made to reduce it in the mine air, and all this residual VAM becomes fugitive emissions. This is what is new and what could change with this work; it has now been shown to be possible to cut VAM emissions significantly, safely, and at a very low cost. Given the rising concern over the ~650Mt CO_2-e in CH_4 fugitive emissions globally which are carried into the environment in the mine air as VAM, and the lack of availability of a safe and cost-effective VAM treatment plant, alternatives for the mitigation of VAM gas need to be available. Especially since VAM fugitive emissions are expected to rise to ~800Mt CO_2-e globally by 2020 (Karacan, Ruiz, Cotè, & Phipps, 2011).

2.3.6 Gas drainage is mainly performed for safety reasons

Gas drainage systems are necessary and do reduce outburst potential and VAM to a level which enables much safer mining. Historically, the only aims of gas drainage measures has been to either increase miner safety, or for statutory compliance with gas limits; no consideration was given until recently to GHG emissions. Much greater thought has now been devoted to reducing fugitive emissions from mining both in Australia and overseas (Abouna, 2014) (Su et al., 2006) but with limited success due to VAM plant cost, safety and running problems (Mattus, 2017). Essentially, perhaps due to the VAM plant impasse, little is being done at most collieries in Australia to target post-gas drainage, residual VAM fugitive GHG emissions in order to reduce the mine's carbon footprint. There are some exceptions to this (Packham et al., 2011) (Guo et al., 2015), but the VAM reduction achieved, is still incidental to the main aim of the gas drainage works. Some recent modeling work has been done in Australia which indirectly reduces VAM gas generation by 'enhanced gas drainage methods' (Packham et al., 2011), this involves enhancing gas drainage by using nitrogen injection. Basically, all gas drainage is either aimed at assisting the ventilation system to cope with high gas makes, or to prevent outburst events (Imgrund & Thomas, 2013). Work shows that if gas drainage is done early, up to 70% of the virgin gas can be removed (Zuber et al., 1999).

2.4 VAM mitigation difficulties

Although much work and several trials of VAM reduction plant has taken place over the last two decades, the technology to eliminate VAM emissions is presently a work in progress (Baris, 2013); VAM is seen as a particularly difficult problem once it reaches the mine fans (Karakurt et al., 2011). An increase in VAM gas emissions in Australia is anticipated in all future scenarios (Figure 2.8), because of projected increases in coal exports, the mining of lower, gassier seams, and the lack of an alternative VAM mitigation methodology. From 2022 the use of VAM plants is expected to reduce this source of emissions, however, there are large uncertainties in the projected numbers (Authority, 2014).

Attempts thus far to deal with the fugitive emissions aspect of the VAM gas problem have centered around treatment after the VAM reaches the main exit fans. Because the VAM concentration in the mine air can vary enormously from mine to mine (Zhao et al., 2012), and from one minute to the next at the same mine (Saghafi et al.)(1997) and the mine air often contains contaminants that affect catalysts, many problems arise when using a typical thermal oxidizer mitigation plant (Ciambelli et al., 2001) (Su et al., 2006) (Gosiewski & Pawlaczyk, 2014) (Somers & Schultz). When fed relatively clean air, a low feed rate, and a regulated CH_4 concentration of 0.6% to 1%, these plants can operate well, and achieve a 97% CH_4 destruction rate (Somers & Schultz) – but that is not the nature of mine airflows.

VAM emissions for the two largest emitters, China and the U.S. have been estimated by the USEPA at 6.7 billion m^3 and 2.6 billion m^3, respectively. Australia's emissions in 2002 were estimated at 0.7 billion m^3 (Somers & Schultz) (2008). VAM treatment is a very interesting area of research for scientists, engineers and chemists at present. New and promising means of capture are bio-filtration, porous ceramic filtering and carbon fibre composite filters. A 'scrubber' using a CH_4 oxidising bacterium, *Methylomonas fodinarum* was proposed in 1992 (Sly et al., 1993).

2.4.1 Bio-filtration of VAM gas

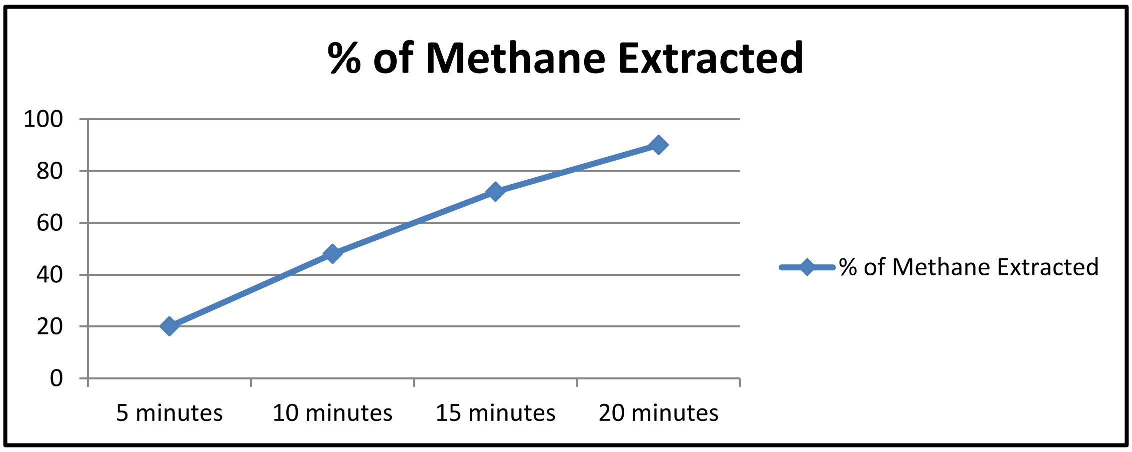


Figure 2.11 Methane mitigation by bio-filtration (Silverman & Ehrlich, 1964).

At air concentrations of 0.25-1.0% commonly found in exiting ventilation mine air, the percentage of the CH_4 removed was found to be dependent on the residence time. Twenty minutes of residence time in the bio-filter removed 90% (Figure 2.11) of the CH_4 present (Silverman & Ehrlich, 1964). Prof Moghtaderi at Newcastle University is also working on VAM a treatment plant, using chemical means to destroy CH_4 (Y. Zhang, Doroodchi, & Moghtaderi, 2014).

2.4.2 The three main types of VAM plants available

These plants are based on catalytic combustion through monolithic reactors and reverse flow technologies and are;

- thermal flow reversal reactors (TFRR) needs 0.2% CH_4 to operate
- catalytic flow reversal reactors (CFRR) needs 0.1% CH_4 to operate
- the CSIRO lean burn turbine and catalytic combustor (CMR) needs 0.4% CH_4

Only the latter plant can be successfully used to generate electricity, although all would still be viable at a carbon credit price of A$10+ (Su et al., 2005).

2.4.3 VAM plant trials

Small-scale VAM plants have and are being trialled is Australia; for example, at Mandalong mine in NSW. This type of VAM plant is a reverse cycle monolithic type reactor – basically a big oven which operates at 1,000°C and burns the VAM gas, converting it to CO_2 with a 99% efficiency. The design features reverse cycling of the mine air which prevents the oven from cooling down; in this way, once it is started it requires no further energy input to keep going, it is self-sustaining. However, there is a cost of several million dollars for this one small plant, a 12 times upscaling will be required if all the mine's VAM emissions are to be treated (R. I. Holmes, 2016b).

Commercial VAM treatment plants are becoming available, the VAM Thermal Oxidiser (VAMTOX) is now a common name for this plant. To operate efficiently, they typically require at least a 0.8% CH_4 concentration in the mine airflow; this often means that a supplemental source of CH_4 needs to be added to the mine air flow to reach this level. An alternative would be to separate the longwall return from the development return flows, and only treat the longwall flow which is generally over 0.8%. However, this has not been done yet at any mine. Other stumbling blocks are safety issues, the very high cost of this form of mitigation, dirty mine air and the effect of this on catalysts used in the oxidiser.

The first successful demonstration of a small scale VAM plant was in 1994 at Thoresby Colliery (Creedy & Tilley, 2003) in the UK, then later at Appin colliery (Limbri, Gunawan, Rosche, & Scott, 2013) and at West Cliff colliery (Yin, Su, Yu, & Weng, 2010) in NSW, Australia. West Cliff VAM plant successfully generated 6MW of electrical power during operation. More recently a VAM pilot project has been undergoing operational testing at Mandalong colliery in NSW (Somers & Schultz) (2008). Mandalong are planning to eventually fully treat all their VAM gas by using a thermal VAM plant. Gaohe coal mine in China is now effectively treating most of its VAM flow (~280 m^3/s) using a bank of twelve large regenerative thermal oxidisers installed by Durr systems. The plant is able to generate up to 30MW of electricity from a mixture of VAM gas and CMM.

2.4.4 Catalytic VAM combustion reactors

Flameless catalytic combustion was probably seen first by Sir H. Davy in 1818 while working on the Davy safety lamp for coal mines. A reverse flow catalytic reactor has also been proposed; a model made and tested in Canada (Salomons, Hayes, Poirier, & Sapoundjiev, 2003). Test percentages of CH_4 used were 0.22%, 0.33% and 1.25%. The aim of the reactor is to contain the heat required for the catalyst to oxidise the CH_4 in complete combustion to CO_2. The catalyst section is important and contains Raschig rings. For CH_4 it is possible to use metal or non-metal catalysts; platinum palladium or perovskite-based are just some examples (Veser & Frauhammer, 2000) (Ciambelli et al., 2001). There are difficulties with all of these new technologies which are all designed to treat the VAM gas when it exits the mine (Su, Chen, Teakle, & Xue, 2008). Some are unproven, some are very expensive, but all reactors have safety issues related to connecting what is basically an oven which operates at least at 500°C (Shah, Moghtaderi, Doroodchi, & Sandford, 2015), to a coal mine which contains flammable gas and coal - and could potentially expel a plug of CH_4 gas within the explosive range. Any method of mitigation used must not reduce the existing safety level of the mineworkers. The mines inspectorate and the respective mine owners and managers need to be convinced of the plant's operational safety.

2.4.5 The six main problems associated with VAM plants

1. Safety. These plants are usually thermal oxidizers, meaning they convert CH_4 into CO_2 by burning it. They require >1,000°C during operation. This is a decidedly dangerous piece of plant to consider operating near a coal mine and connecting it to the mine air flow that may occasionally contain explosive gas mixtures is not something the average mine manager would want.
2. Feed rate. This is typically 10 m^3/s to 20 m^3/s. Most mines operate with airflows in the hundreds of m^3/s. This means that either 90% of the mine air is not treated, or the VAM plant must be 10 times bigger – with a commensurate massive increase in cost.
3. Regulated VAM percentage. Most VAM plants operate best at a steady 0.6% to 1% CH_4 in the mine air. But most VAM gas varies rapidly from 0.1% to 1%, and typically is 0.3%. To fix this problem, regulated feedstock CH_4 must be piped from the mine and added to the mine air prior to lift the VAM concentration and to regulate it. This adds considerable complication and safety issues to the whole operation.

4. Contaminants. Return mine air is often very dirty, and contains water vapour, coal dust, grime and stone dust. The successful Appin colliery VAM electricity generation plant had to be shut down due to the continual fouling of the plant by contaminants (Limbri et al., 2013).
5. Complexity and high technology. Very costly and large machinery.
6. Restricting air flow. As any ventilation expert will attest, putting something in the way of any airflow, amounts to installing a resistance on that airflow – which reduces it. In this case, the required mine airflow can only be restored by the installation of stronger or bigger mine fans, which of course costs a lot of money.

2.4.6 Options to prevent coal mine methane from becoming VAM gas

There are three general options which are available to a colliery which has been classified as a large emitter (of over 25,000 t/CO_2-e/yr) under the NGERS (Lodhia, 2011).

1) Drain as much as possible from the seams, goaf and strata before and during mining, use this gas in power generation and then emit the rest as fugitive emissions and pay for these emissions (if there is a carbon price).

2) As above, but then separate the longwall and development streams and treat the higher concentrations in the longwall stream by using a VAM plant, buy credits as required for development emissions.

3) As 1; but then treat all VAM as it exits the fans in a large VAM plant.

Which of these three is chosen will depend on several factors, these are;

- the amount and the type of gas in the seams/strata
- the cost of carbon credits and their availability
- the availability of funding from government under such plans as 'direct-action'
- how difficult it is to separate the longwall gases from the development gases
- the relative concentrations of VAM in each return; longwall and development
- what gas drainage methods are or have been in place
- the concentration of VAM gas at the fans
- what legislative controls are in place
- the state of VAM mitigation technology and its availability/cost/safety record
- what government incentives are available to reduce emissions

Use either of the first two options to reduce fugitive CH_4 emissions, and the mitigation method used in the 12-month trial (details below) can still be used to cost effectively reduce the amount of CH_4 which enters the mine air to become VAM.

2.4.7 Separating the long-wall and development returns

VAM treatment by oxidation or other means is a new technology which has yet to see widespread application, but this method could be implemented sooner if the longwall and development returns were to be separated. This would make VAM treatment of the longwall portion of the returns easier because the longwall concentration of VAM is generally higher than development returns, because more coal is mined there which releases more gas. Longwall returns contain typically 1% VAM whereas development returns contain much less, typically 0.1% VAM, and when the returns are combined, the VAM concentration is generally around 0.3%. It is considerably easier technically, to treat VAM at 1% than at 0.3%. (Y. Zhang et al., 2014) Separating the returns could obviate the need to inject high-concentration drainage CH_4 into the mine airstream to lift VAM concentrations sufficiently for the VAM plant to operate well, as is the current practice; this simplifies matters.

2.4.8 The difficulties of reducing VAM emissions

At present, the majority of the typical collieries' greenhouse emissions are the residual fugitive VAM gas, and it remains as the most intransigent of the mine emissions to mitigate because of its low concentrations. This is typically 0.2% - 0.5% in the high-volume mine airstream. Although much research is currently underway to treat VAM using various means, including destruction by heating in a reverse-cycle catalytic converter plant, and chemical treatment methods, this new technology has yet to be universally accepted as being both safe and cost-effective on an industrial scale. The technology will not see wide application until that is the case; meanwhile, another method of reducing VAM fugitive emissions is needed. Enhanced pre-mining gas drainage methods have been proposed (Packham et al., 2011), which may indirectly work to reduce somewhat VAM emissions in an Australian context, but this method will strike problems in some other countries. For example, in the US, there are issues with ownership of the gas, if more is taken from the seam than is needed for purely operational and safety reasons; the same applies in India. In China, most drained CH_4 is below 30% in concentration; creating serious safety issues with drainage, in addition there are limited drainage technologies, and poor access to reticulated gas pipelines. Russia also suffers from low-grade coal seam CH_4 and has the added problem of low-permeability seams. Yet these countries are the ones which emit most of the planet's fugitive VAM gas.

Post-mining emissions have also been considered, especially from the hundreds of abandoned mines in the UK (Jackson & Kershaw, 1996). The method outlined in this research, will reduce VAM emissions safely, no matter what the seam concentration is. Global fugitive emissions of VAM were 630 Mt CO_2-e in 2015 (U.S. EPA) (Figure 2.3), this is a significant 1.5% of global man-made GHG emissions.

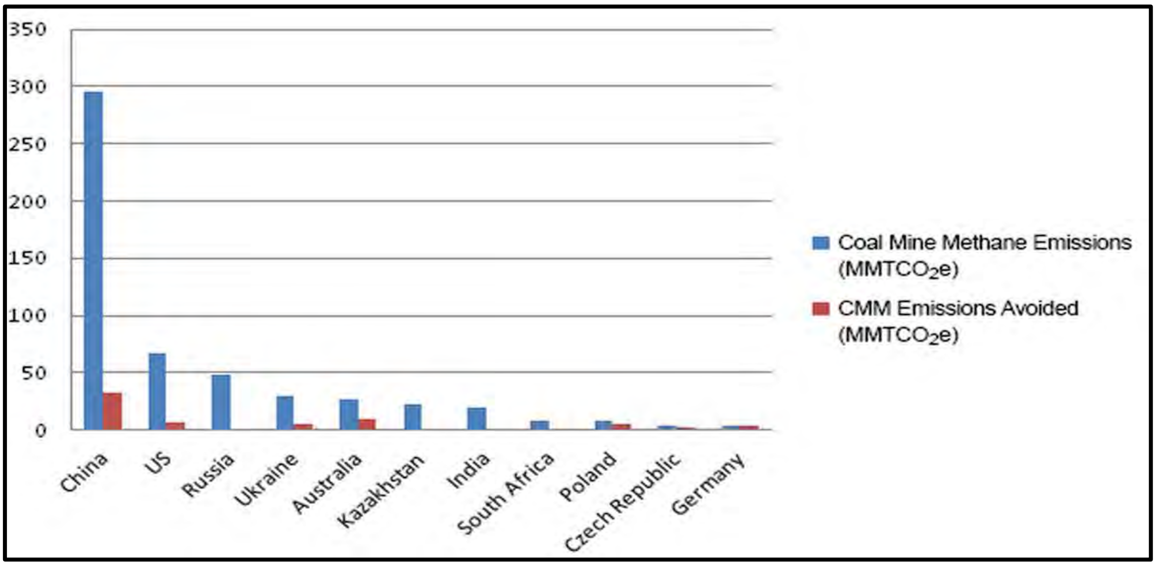


Figure 2.12 Coal mine methane emissions in 2010 by country (U.S. EPA, 2017)

2.4.9 VAM estimation methodologies

Whole-mine VAM make estimation is typically made across whole months and financial years, using continuous records from single real-time or tube bundle CH_4 detectors located at each of the mine's exit fans (Holmes, R. 2009). Importantly, the method being used for VAM make estimation for each specific ventilation circuit under this study needs to supply an accurate figure for the VAM make in that circuit across time, so that an accurate estimate of any mitigation can be made. However, this does not mean that the VAM measuring and estimation method must be identical across all circuits and all mines. In any case, this type of uniformity of measuring method across the different circuits and mines proved to be difficult if not impossible in practice.

2.5 What more could be done to reduce VAM fugitive emissions?

As noted above, it is the case at present (2017) that VAM plants are not being used widely. Those which are in use are undergoing small-scale trials and it would be true to say that in fact, little is actually being done to reduce VAM fugitive emissions either in Australia or overseas. The VAM plant impasse may have caused a situation to develop where any thought by mine managers of dealing with residual VAM was simply put onto the back-burner and put into the too difficult basket. Recent work listed seven different ways to deal with VAM (Limbri et al., 2013). There is an eighth; VAM can be reduced substantially in another way, without using a VAM plant or biofiltration – the eighth way is the focus of this work.

In chapter five, details are provided about a method which was trialled in a NSW colliery involving six measures that was specifically aimed at reducing VAM creation. There is nothing new about these measures to underground coal – only the fact that in this case they were specifically used to reduce residual VAM emissions, and that the results were quantified, costed and published. Although this method did not reduce fugitive VAM emissions to near zero levels, as is the aim of the operators of the VAM plants, there was a significant effect on overall VAM emissions, reducing them by an estimated ~20%. A further reduction to ~35% or perhaps more below projected levels, is a distinct possibility. Although this will come only at a higher abatement cost per tonne than the A$1.08 average which was achieved during the trial. The achieved cuts convert into an annual total target for VAM abatement, if the practice were implemented across Australia's 30 VAM-affected collieries, of between 3Mt/CO_2-e and 5Mt/CO_2-e per year. Since the average car emits 4.7t of CO_2 per year (EPA, 2017), this is the equivalent in terms of GHG emissions averted, to taking almost 1 million cars off the road. This represents a significant 0.7% of Australia's total GHG emissions.

Safety is also vital in coal mines and this is where the six mitigation measures that were used in the 12-month trial (results are detailed in Tables 5.10 and 5.11) have the advantage over VAM destruction by heat; they are not only completely safe, but by their nature the application of any of them individually, improves mine safety further. Proving all six measures at other mines was beyond the scope of this work; two of the measures were considered to be sufficient to validate or invalidate the method. Therefore, the two most successful of the six measures were selected to be used to validate or invalidate the proposition that the mitigation levels and costs achieved in the NSW trial are transferable to other large collieries. This 'transferable' test was performed by measurement and modelling of Mine A and Mine B data and the results are presented in chapter six.

Safety gains, in the case of the validation testing modelling performed on Mine A and Mine B data, are quantified in chapter seven. Any concerns about these mitigation measures therefore will not come from the point of view of safety, but only from a cost or a willingness to implement perspective.

2.5.1 The effect of emissions schemes on mitigation results

The manner and amount in which fugitive GHG are mitigated depends to a large extent on how much they are taxed or how much is available for mitigation through schemes like direct-action, and what mitigation is specifically covered by those schemes. VAM plants are covered by direct-action, however there are serious safety concerns in collieries when attempts are made to attach VAM gas plants to the main fans. Most VAM plants are basically a huge oven, which destroys CH_4 by burning it at 1,000^{o}C (Y. Zhang et al., 2014). The idea of connecting a VAM plant to a colliery is meeting stiff resistance from many coal mineworkers and managers. Even flaring drained high % CH_4 has met stiff resistance to date in the USA; a practice that is used safely in Australia and is arguably safer than a VAM plant is perceived to be (Karacan et al., 2011). It is a fact that coal miners and coal mine managers are rightly cautious when it comes to safety, especially about ignition sources. In Australia, smoking is not permitted anywhere on site, many everyday items such as cameras and phones, are classified as contraband and not permitted into the mine.

2.5.2 Using mine air as generator feedstock

Exhaust mine air can be used as feed-stock air to a generator set (genset) (Figure 2.4). This not only destroys the CH_4, but uses all of the feed VAM to generate power in the genset. In a world's first commercial use of VAM, the Appin colliery in NSW, Australia used 20% of its exhaust mine air to feed 54 x 1MW gas gensets which it runs on site from its gas drainage system. 65 m^3/s of the mine air was filtered for dirt and then fed to the engines. The VAM content was estimated to add 4 to 8MW to the output of the gensets, resulting in an average power generation of 55.6MW, which was on-sold to a utility (Su et al., 2006). Because the feed air is not ignited until it is inside a genset cylinder, this method is seen as safer than some of the alternative methods of VAM gas destruction; however, some issues still remain. There must be no point at which exhaust mine air, (which could contain a plug of flammable CH_4 gas) might contact surfaces of high temperatures and ignite. Strict controls have to be enforced between the point where mine air exits the fans and the point where the high temperatures in the gensets exist. But problems were still encountered, using the dirty mine air as feedstock air for the gensets was discontinued due to the very frequent cleaning required which caused cost inefficiencies for the operation (Limbri et al., 2013).

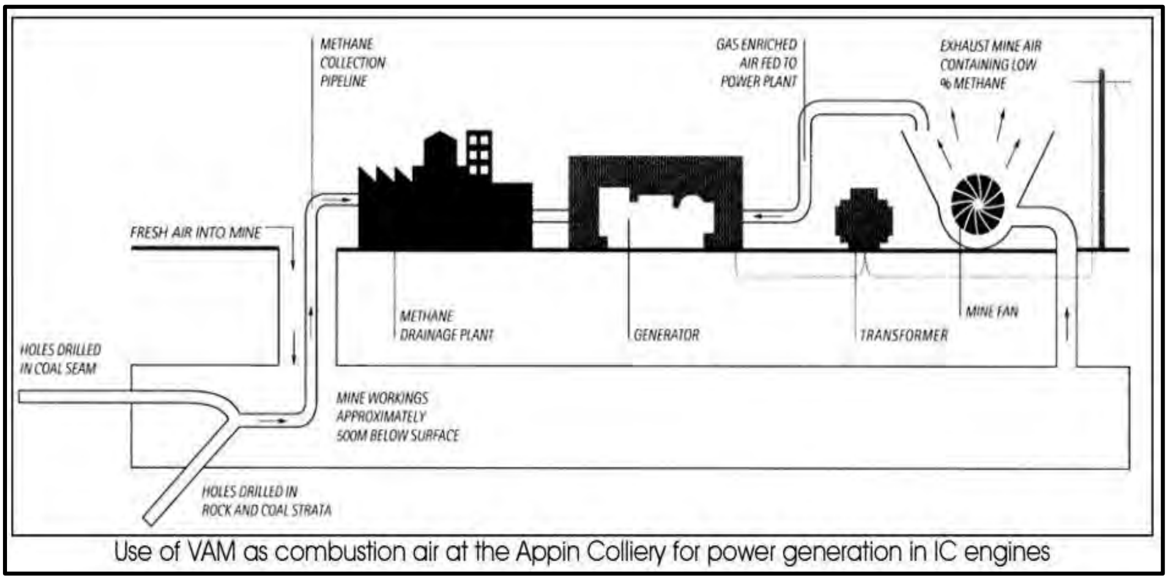


Figure 2.13 Appin colliery; 65 m^3/s of mine exhaust was used as feed air for gensets

The concerns raised by connecting a VAM plant directly to the mine fans centre around CH_4 gas, which is explosive in air when between 5% and 15% concentrations. If the mine were to expel a plug of CH_4 through the fans at 5%+ concentration, due to the failure of a seal, or a gas outburst event for example, this could prove to be catastrophic. If ignited by the VAM plant, the flame would propagate all the way back through the mine to the source of the gas leak and could trigger a dust explosion. Hence the reticence of some mine managers to even consider such an idea. Occasionally, the two aims of not reducing mine safety levels in operation and the desire to mitigate emissions to either reduce carbon tax costs or obtain revenue from schemes like direct-action, conflict. These conflicts should be identified and dealt with in any good, comprehensive risk assessment process. As always, the safety of the mineworkers must take precedence over any thought of mitigation of emissions; that is why even if VAM plants do become viable and are deemed to be 'safe' resistance will still be met in the widespread application of this new technology.

2.6 Methodological framework of this work

This work will first describe the context of the research, which includes the concern over GHG, their effects on the environment and the resulting governmental regulations and emissions targets. It will include an evaluation of the current state of the science of global warming in chapter three. This will answer the first secondary research question and is important to help to clarify the real state of the climate science in the literature, in order to assess or predict likely future governmental regulatory actions. Chapter four will examine the politicisation of the field of climate, and how this is affecting the wider international climate debate and the emissions-reduction response required to climate change.

How CH_4 mitigation was achieved during the 12-month trial is to be covered in chapter five, including quantification of abatement and the costings related to each of the six measures used. The best two measures of those six will be assessed for mitigation performance in chapter six, the Mine A and Mine B modelling project, which will answer the primary research question. The implementation of these two measures will then be assessed in chapter seven for their impact on safety during actual mine operations. Chapter 7 will cover the carbon credit generation and the public relations benefits respectively. As part of this overall process, two large Australian longwall mines will be visited (Mine A and Mine B) where the following data will be collected;

- Real-time and tube-bundle data
- The main fans and secondary fan pressure and flow data
- Surface pressure data including diurnal changes
- Ventilation survey data
- Gas monitoring arrangements
- Pressure survey data from relevant seals
- Gas and airflow survey data from general body in relevant panel returns and intakes
- Latest Ventsim file
- Mine plan

The collated data is basically a numerical representation of the methodology that can be used to solve the primary research question. The VAM gas data is to be collected in the following way, and generally presented in a graph format or modelled in a Ventsim simulation.

- Gas data from safegas in excel sheet form
- Fan, flow and pressure data from the monthly ventilation reports
- Pressure measurements direct from relevant seals
- Gas and airflow measurements directly from relevant roadways
- Modelling data from Ventsim Visual ventilation software
- Surface pressure data from the mine barometer

2.6.1 This project will add to the knowledge base

No papers could be found in the worldwide literature which specifically detail the prevention of CH_4 from becoming VAM fugitive emissions purely for environmental reasons during normal production in longwall coal mines. Some papers were found which involved standard methods such as CH_4 drainage using surface or underground bore-holes. However, the main aim of the CH_4 drainage in most cases was safety-oriented or for statutory compliance reasons, that is; aimed at keeping the concentration away from the explosive range rather than aimed specifically at GHG mitigation. In some other cases, the drainage was fuel-based – aimed at using the CH_4 as a resource. A recent attempt to improve control over gas flows was tried at Blakefield South, which is an extension of an old colliery in NSW. This mine planned to mine large long-walls in a high methane make environment by utilising innovative but complicated push-pull ventilation methods to control high and challenging gas flows (Guo et al., 2015) and to reduce pressure differences to old, shallower workings. This could be seen as an attempt to reduce excessive VAM gas emissions by exercising pressure control over open and sealed goafs, but its focus was nevertheless on gas management from a safety and statutory compliance viewpoint (Qu et al., 2016).

3 Chapter 3: The science of global warming

Secondary research question i)

"How solid is the scientific evidence behind the desire to reduce emissions of GHG?"

3.1 Background to the concern over global warming

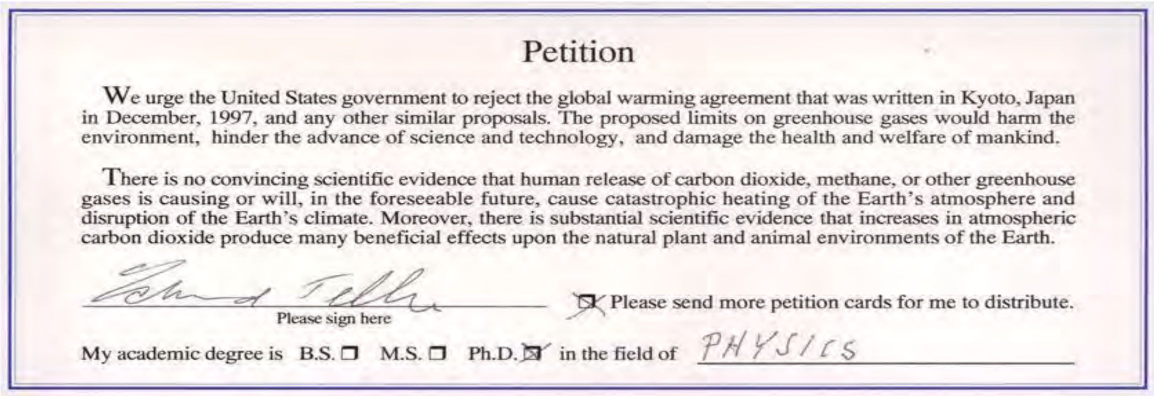
GHG such as CO_2 and CH_4 do not fall easily into the category of 'pollutants', so how should they be classified? Why do they need to be regulated? It is the concern over what was initially called 'man-made global warming' and more recently, is now called 'man-made climate change' that is driving many governments and many concerned individual's desire to cut human emissions of GHG, principally CO_2 and CH_4. The cost of cutting these emissions so far in Australia is already in the many tens of billions of dollars, and these costs are likely to continue, and even grow in the foreseeable future. Questions must therefore be asked and answered about what Australians are getting in return for this massive expenditure. One of the main ones needs to be; why hasn't any federal or state government performed a single cost/benefit analysis of this spending? Another question is; what is the scientific evidence which has given rise to this concern, and is there any real cause for the alarm over the climate, which exists in some quarters? Given the huge resources of people, time and money that Australians are spending on this issue, as opposed to the very many other pressing issues that the nation has, a serious and unbiased examination of the scientific drivers of the concern about the climate is needed. The politics of climate is also important; chapter three will consider scientific evidence as found in the literature, and chapter four will examine the politics of the climate issue.

3.1.1 The IPCC reports and their critics

It is a fact that climate change cannot possibly be caused by anthropogenic emissions of GHG, unless they cause global warming first. The available scientific evidence that these emissions are the cause of recent global warming, and will cause much more future warming if they are not drastically reduced, has been presented in a series of reports, organised by the UN's IPCC. These reports (or at least their much shorter summary reports) are well known, and have been widely read, reported and commented on in the media. These assessment reports are compiled and released every few years and are;

- IPCC First Assessment Report 1990 (FAR)
- IPCC Second Assessment Report 1995 (SAR)
- IPCC Third Assessment Report 2001 (TAR)
- IPCC Fourth Assessment Report 2007 (AR4)
- IPCC Fifth Assessment Report 2013/14 (AR5)

Many say that these reports are representative of the state of the science of climate change, as revealed by the relevant peer-reviewed journals – the scientific literature. But others say that they do not tell the whole story, and that the IPCC reports represent only one side of the climate story, since they leave out a large portion of the science of climate change – specifically; those papers about natural variability, astronomical cycles, solar variability, cosmic ray effects, the role of clouds and auto-compression among others. Who is saying this? Tens of thousands of scientists in the Oregon petition project (Figure 3.1).



Petition

We urge the United States government to reject the global warming agreement that was written in Kyoto, Japan in December, 1997, and any other similar proposals. The proposed limits on greenhouse gases would harm the environment, hinder the advance of science and technology, and damage the health and welfare of mankind.

There is no convincing scientific evidence that human release of carbon dioxide, methane, or other greenhouse gases is causing or will, in the foreseeable future, cause catastrophic heating of the Earth's atmosphere and disruption of the Earth's climate. Moreover, there is substantial scientific evidence that increases in atmospheric carbon dioxide produce many beneficial effects upon the natural plant and animal environments of the Earth.

Please sign here ☒ Please send more petition cards for me to distribute.

My academic degree is B.S. ☐ M.S. ☐ Ph.D. ☒ in the field of PHYSICS

Figure 3.1 The statement in the Oregon petition project (Petition project, 2017)

Over 9,000 PhD's have signed, even though this list is restricted only to U.S. citizens; many are professors in their fields, and some are high-profile individuals. To be a signatory, the wording in the petition needs to be agreed to, possession of a Batchelor's degree or higher in the sciences is needed, and a signature is required.

3.1.1.1 The 1,000+ dissenting international scientists list

International scientists who disagree with the extent of the scientific coverage of the IPCC reports, or are otherwise dissatisfied with them, have made themselves known in a U.S. Senate minority report (U.S. Senate, 2008). These 700+ scientists have a wide range of views, which they express in their own statements; however, all are dissenters from the state of the science of climate as expressed in the IPCC's general reports, but most especially in the summary reports for policy-makers. (The dissenting scientists have, since the report was tabled, expanded in number to over 1,000 (Australian Government, 2017)).

Scientists on this list are people like Nobel prize-winning physicist Ivar Giaever, Nobel prize-winning physicist Robert Laughlin, climatologist Hans Jelbring, atmospheric physicists John Reid and MIT professor of atmospheric physics Richard Lindzen, physicist Hal Lewis, climatologist Judith Curry, physicists Fredrick Seitz and Freeman Dyson; Princeton's professor of physics William Happer and many, many others. Should these scientists be ignored? Or should the old Russian proverb be applied; *'Trust, but Verify',* and look into the literature for what has been called; *'The Missing Science'* (Plimer, 2009)? To a scientist, the latter is the best course of action; all currently known climate science will be covered, and the state of the science of climate change discussed in detail in this chapter.

3.1.2 The alarm is raised

Concern over anthropogenic GHG emissions has been there for decades; founding work by Svante Arrhenius (1859-1927) claimed that the GHG released by burning fossil fuels might lead to global warming (Arrhenius, 1896). Early climate computer modelling work by James Hansen, head of the Goddard institute for space studies 1981-2013 (GISS) (J. Hansen et al., 1984) indicated that there was reason to worry about the rapidly growing GHG emissions. James Hansen subsequently raised the alarm before congress in 1988 (J. Hansen et al., 1988) twenty years later in another briefing before congress he warned that;

"Climate tipping points were near". (J. Hansen, 2008)

The strongest GHG is water vapour (Schmidt et al., 2010) with 75% of the total effect, but humans emit insignificant amounts of this gas; it is CO_2 which is both emitted in large quantities by human activity, and represents a significant portion of the total greenhouse effect at 20%, which is the main concern. CO_2 is a 'dipole' molecule and as such will only temporarily absorb electromagnetic radiation of a certain wavelength, and then conduct away or re-emit this energy in a random direction. If they re-emit a photon, CO_2 molecules will re-emit ~50% of the energy they absorb, back down to the ground. Another GHG released by human activity, is CH_4, which is ~1% of the GHE. Other atmospheric molecules, such as O_2 and N_2 are not dipoles, so they will not absorb these outgoing photons.

The Earth's surface has an average temperature of 288 Kelvin and as such radiates its infra-red heat away, in a black body curve which approaches the Planck function (mainly in the 5 to 33-micron band with the peak at ~17 microns). The photon wavelengths that CO_2 will absorb is in the 12 to 17.6 micron band in the so-called infrared window. CO_2 is of concern because of its bite above the infrared window, centered on 15 microns. The oceans in particular approximate a black body response curve, to within 1% (Buettner & Kern, 1965).

In 1992, John Houghton, the lead editor of the first three IPCC reports, co-chair of the IPCC and former director of the UK's weather forecaster, (the MET office) warned that if 'business as usual scenarios' are continued, by 2030 a 2.5°C rise will be locked into future global warming (J. Houghton, 1992); and that because of increasing anthropogenic GHG emissions, a 0.25°C per decade rise in global temperatures between 1992 and 2030 is to be expected. In an interview with Frances Welch in 1995, Houghton is quoted as saying;

> "God tries to coax and woo, but he also uses disasters….If we want a good environmental policy in the future (then) we'll have to have a disaster" *(John T Houghton, 1996).*

Are these the words of an unbiased scientist? Another early proponent of what became the enhanced greenhouse gas warming hypothesis (henceforth EGGWH) was mechanical engineer Stephen Schneider, lead author of WG2 in the IPCC's TAR, a prolific author of over 450 scientific papers, and founder of the journal 'climatic change'. Schneider was the climate advisor to the premier of South Australia Mike Rann. It was Schneider who famously said in a 1988 discover interview;

> *"On the one hand, as scientists we are ethically bound to the scientific method, in effect promising to tell the truth, the whole truth, and nothing but – which means that we must include all doubts, the caveats, the ifs, ands and buts. On the other hand, we are not just scientists but human beings as well. And like most people we'd like to see the world a better place, which in this context translates into our working to reduce the risk of potentially disastrous climate change. To do that we need to get some broad-based support, to capture the public's imagination. That, of course, means getting loads of media coverage. So we have to offer up scary scenarios, make simplified, dramatic statements, and make little mention of any doubts we might have. This "double ethical bind" we frequently find ourselves in cannot be solved by any formula. Each of us has to decide what the right balance is between being effective and being honest. I hope that means being both."*
> *(Marchudson, 2016)*

Statements like this by a handful of scientists who are leaders in the field of climate are all too common, and can reasonably bring to the fore questions about their scientific impartiality and honesty in that field. Scientists should strive to be impartial and not become advocates; it hardly needs to be said that in order to effectively follow the scientific method assiduously, one needs to be unbiased, impartial – and honest. It is also vital that when scientists are advising policy-makers, that they disclose not only what they know, but what they don't know – and what they are unsure of.

3.1.2.1 Doubts about the science grow after 2006

The good reputation of the global warming movement with the public, (as it was in the late 20th century) lost ground with these events;

- The 'hockey stick' controversy (D. Holland, 2007), and the related U.S. Senate/Committee on Energy and Commerce investigation into it (Wegman, 2006)
- Al Gore's book and film (Gore, 2006) titled 'An Inconvenient Truth' was released in 2006, and was subsequently shown to have 9 significant scientific errors in London's high court by Justice Burton (Mellor, 2009)
- In 2009, when the so-called climategate emails were released, revealing possible groupthink among a small number of climate scientists (Ravetz, 2011)
- It was revealed during the email investigations that the UK's climate research unit did not comply with FOI requests to supply temperature data (Grundmann, 2013)
- A whistle-blower at the national oceanic and atmospheric administration (NOAA), Dr John Bates, came forward in late 2016 and exposed the 2015 'Karl study' (Karl et al., 2015) which originated at NOAA. This study attempted to re-write – just before the Paris COP21 climate conference – the previous 20 years of global temperature data, which was unanimous in that a temperature 'hiatus' or 'pause' was happening. Could this have been an attempt to influence the outcome of the Paris meeting? This matter is currently under investigation by the U.S. house on science, space and technology (U.S house, 2017)

3.1.3 Polls reveal little concern by the public

The United Nations runs a yearly poll called 'Have your say' because they; 'Want to know what matters most to you'. From a list of 16 concerns, 'Action on climate change' came in last (Have your say, 2015).

3.1.3.1 First generation to fear warming

This may be the first generation ever to fear warming. Generally, cold has been the temperature change to be feared, and with good reason; it is clear that cold kills far more people than warmth, in fact at a ratio of 17:1 (Gasparrini et al., 2015). Historically, warm periods have been times of plenty, stability and advancement, and have been called ‘optimums’ such as the ‘Medieval climate optimum’ the ‘Holocene climate optimum’ etc. Cold periods have been associated with wars, famines, disease and extreme weather patterns, such as the early 19th century ‘Dalton minimum’. Considerable scientific as well as historical evidence supports this.

A report (Leviston, Price, Malkin, & McCrea, 2014) by CSIRO shows that climate change is presently very low on the list of concerns for Australians, being ranked 14th in general concerns, and 7th out of 8 even among environmental concerns. Surprisingly, although this poll was called a *‘Survey of Australian attitudes to climate change’* it never defined what was *actually* meant by the term *‘climate change’*. As will be discussed in the next chapter, there are at least three definitions of the term in general use, which obviously results in considerable confusion among the public as well as among policy-makers. However, when questioned closely, the Levison survey reveals that less than half of the public (47.3%) actually thinks that climate change is happening and that the cause is mostly anthropogenic. The majority (52.7%) either think that climate change is happening, but the cause is wholly natural, or that climate change isn’t happening, or just don’t know if it is happening or not. These responses are very far from the 97.3% consensus among climate scientists, that is claimed in the literature (Anderegg, Prall, Harold, & Schneider, 2010; Cook et al., 2013). However, the results of the Anderegg study have been strongly disputed (Tol, 2014) as has the Cook study (Legates, Soon, & Briggs, 2013; Tol, 2014).

3.1.4 Opinions among climate scientists or climatologists

3.1.4.1 Who is and who isn’t a climate scientist or a climatologist?

In this new field of climate science there is also much conjecture about who is and who isn’t a climate scientist or a climatologist. Again, this seems to be subjective rather than a matter of defined qualifications. Persons who have an undergraduate university degree of some sort, and work in the general field of climate science, may self-describe themselves as ‘climate scientists’ – even though they may have no university qualifications whatever in any science subject. Others, who may appear to the unbiased observer to be highly qualified to speak on the subject, for example professors of physics, planetary atmospheres or paleoclimates may be regarded by some to be unqualified to speak on climate, if they do not publish in the top-ranked climate journals.

Of course, this bias may be more a result of the listener’s world-view being challenged by the speaker, rather than any actual lack of qualifications to speak on the subject. The IPCC must take some of the blame here, since they have confused matters. Their reports contain three main sections, and have had from the publication of their first major report in 1990, which became the basis for the work of the UNFCCC. The sections are;

- Working Group I (WG1)– The Physical Science Basis
- Working Group II (WG2) – Impacts, Adaptation and Vulnerability
- Working Group III (WG3) – Mitigation of Climate Change

It may appear to be a mystery as to why WG2 and WG3 would be required in the first report, before WG1 have established the following; first, if man's emissions are affecting the climate, and secondly if those effects are adverse, and thirdly, if they will be adverse enough to warrant any action to reduce emissions, and fourthly, if those actions will pass a cost/benefit analysis.

WG1 attempts to set out the attribution – what caused the global warming that has been seen recently – and calculates the climate sensitivity to CO_2. This is by far the most important of the three because if the climate sensitivity to CO_2 (and the other man-made GHG) is very low or zero, then the other two groups are obviously not needed at all. What would be the impact of almost nothing? How vulnerable would species be to no change? What mitigation would be needed to correct basically no change? Yet even though all the scientists (or researchers) in the latter two categories may know little about the physics of the GHE, and whose work may be totally irrelevant anyway depending on the outcome of the attribution research in WG1, they are still counted in many quarters as climate scientists, and still get their views heard in polls on the science of global warming. Even within WG1, most of the scientists do not work on the physics of the Sun, the atmosphere or the climate; they are in the main, computer modellers – experts in that field.

Really, the key players in the whole of the IPCC report are the ones who work on attribution; on the physics going on in the Sun or the oceans, the atmosphere and in the space above it, these are the scientists who investigate the causes of the current period of global warming. Out of the 1,200 in total who worked on the latest IPCC report (Team et al., 2014), and the 255 who worked on WG1, only 18 actually worked on attribution, and three of these were yet to complete their PhD's. Of note is that most reports had just one solar expert, until AR5 which used two.

3.1.4.2 Polls among climate researchers

Several polls have of course been taken of the views of climate scientists, climatologists or climate researchers on the state of the science; other polls have been carried out on the published literature itself. An examination of the 2008 Bray & Storch poll revealed that 78% of the participants described themselves as being primarily involved in modelling and model development (Bray & von Storch, 2010) with most of the others working on impacts. A recent more comprehensive poll of 1,868 climate researchers (Verheggen et al., 2014) found that 65.9% of those polled, thought that more than half of the global warming since 1950 was caused by human-induced rises in GHG; 34.1% thought it was less than half, or didn't know. Do these numbers represent a scientific consensus? To clarify the meaning of the term 'climate or scientific consensus'; - just what is the IPCC consensus statement in AR5?

3.1.5 The AR5 statement on attribution is the basis of the climate consensus

The AR5 statement (Team et al., 2014) on attribution, or what caused the recent warming, is the basis of the consensus in the field of climate, and it is very specific;

> *"It is extremely likely (95%+ certainty) that more than half of the observed increase in global average surface temperature from 1951 to 2010 was caused by the anthropogenic increase in GHG concentrations and other anthropogenic forcing together."*

Bearing this statement from the IPCC in mind; question 1a in the Verheggen poll found that 65.9% thought man caused more than half of the warming since 1950; these people were then asked about their level of confidence in this answer, in question 1b. Here, 65.2% expressed a 95% or higher certainty – thus paralleling the AR5 statement on confidence in the attribution. Therefore, since the probability of two related things is the product of the probability of each separate thing. The percentage of climate researchers who agreed with the above IPCC AR5 consensus statement then must be;

65.9% x 65.2% = 42.9%

This actual figure of agreement with the IPCC's climate consensus statement is 42.9%. This result is from the most recent and very comprehensive 2015 Verheggen poll, seems to be far from, and completely at odds with the '97% consensus' agreement claim which is often heard, and is the headline result from three other polls, (the latter two actually involving a co-author of the Verheggen poll) (Anderegg et al., 2010) (Cook et al., 2013) (Cook et al., 2016).

Note that the consensus statement in AR5 hedges its bets somewhat by including 'other anthropogenic forcing', not only GHG forcing. These could be land use changes, forest clearing, building, power station and vehicle heat pollution, dams, animal husbandry or any number of other human forcing on the environment. Many anthropogenic effects on the environment are not well constrained, and it is even conceivable for the IPCC's consensus statement to still be correct without any contribution to the warming stemming from man's GHG emissions. If this is the case, any action to reduce GHG emissions will not be treating the cause of the warming and naturally will be futile. Amongst all this, the public and some politicians seem to be oblivious of the fact that science is not done by consensus; rather, it is done by guessing, measurement, postulates, hypothesis and hypothesis testing. However, it is true that politics is done by consensus – as is the IPCC's short and readable 'report for policymakers', which accompanies each of its voluminous 1,000+ page 7-yearly scientific reports. Every word of the report for policymakers has to be approved by bureaucrats from each of the 192 participating states and the EU.

Top scientists have pointed out that even though science is not done by consensus, a 'natural' consensus among scientists can exist on some topics. However, the claimed 97% consensus on climate change has been described as a 'forged' consensus, and not a 'natural' consensus, because it involves forcing distant projections of climate models by increases in atmospheric CO_2 (Lindzen, 1996). Climate scientist Judith Curry has also described the consensus as being 'manufactured' (J. A. Curry & Webster, 2013) the constant citing of which, she says, has caused several unintended consequences, including the diminishing of public trust in the IPCC and their processes and projections. The IPCC seems to agree about the low likelihood of any future climate projections from any computer modelling being accurate, since in the executive summary of TAR they state quite clearly and finally;

> "The climate system is a coupled non-linear chaotic system, and therefore the long-term prediction of future climate states is not possible" *(Griggs & Noguer, 2002)*.

Hence, the scientists who write the scientific reports, are trying to communicate to policymakers that there exists a distinction between *prediction* and *projection* (or scenario) and that climate changes can be both abrupt and unpredictable – whether man-made or not.

3.2 The greenhouse effect

"The greenhouse effect (GHE) on Earth is identified by the difference between the effective radiating temperature of the planet and its surface temperature". *(Berger & Tricot, 1992)*

Should the GHE be defined as a temperature difference in this way? Are factors other than the GHE partially or wholly causing this temperature difference? This needs to be investigated further.

The effective radiating temperature of a planet is obtained by applying the Stefan-Boltzmann (henceforth S-B) law for black bodies, in this case to the grey body Earth This law states that the amount of electromagnetic radiation - here, infra-red radiation - emitted by an object is related to its temperature in the following way;

$$j^* = \sigma T^4 \qquad (1)$$

Where;

j^* = energy flux = Joules per second per square metre or watts per square metre

σ = Stefan-Boltzmann constant = 5.6704×10^{-8} W / $m^2.K^4$ (m = metres, K = Kelvin)

T = temperature in Kelvin

R_e = Radius of Earth

Ks = Solar constant

Thus at 100 K the energy flux is 5.67 W/m^2, at 1000 K 56,700 W/m^2 and so on.

The Sun's emissions curve approximates a theoretical black body radiative curve, as do other stars. As a close approximation of a theoretical 'black body' Earth will absorb all the radiation which falls on it and then re-emit that radiation in what is called a black body radiative curve. The total infra-red energy emitted by the theoretical Earth will be;

$$E_{emitted} = \sigma T^4 \times 4\pi R_e^2 \qquad (2)$$

The fraction of the incoming solar energy scattered back to space is referred to as the planetary albedo; for Earth this is 29% or in fractional units, 0.29 (Stephens et al., 2015). The effective radiating temperature of Earth is calculated by;

$$T = \sqrt[4]{\frac{Ks \times (1\text{-}albedo)}{4\sigma}} \qquad (3)$$

Solar constant is 1,366 W/m^2 (Rouzé et al., 2014)

The albedo is 0.29

Stefan-Boltzmann constant is 5.6704×10^{-8} watts / $m^2.K^4$

0°C = 273.15 K

$$T = \sqrt[4]{\frac{1366 \times (1-0.29)}{4 \times 5.6704 \times 10^{-8}}} = 255.7\ K$$

Therefore, Earth's effective radiating temperature is 255.7 Kelvin (or -17.5°C).

The Earth's measured average surface temperature is 287.3 Kelvin (or +14.2°C).

The GHE, - where GHG in the atmosphere absorb and then re-emit Infra-red radiation - is then taken by the IPCC and some scientists to (Pachauri et al., 2014; Schmidt et al., 2010) have caused the entire difference between these two, which in this calculation is;

$$GHE = 31.7°C$$

Note that some researchers reach slightly different numbers for the GHE, such as 33°C (Schmidt et al., 2010) this is due to other figures being used for global surface temperatures, TSI and for the albedo (J. Hansen, Sato, Russell, & Kharecha, 2013). However, there is the distinct possibility that the actual effect of greenhouse gases on atmospheric temperatures is very different from this figure; a possibility which arises from the physical nature of the atmosphere, as will be shown. The 33°C temperature difference could then be more accurately referred to as an *atmospheric thermal enhancement*.

Because the Earth has an atmosphere, the effective radiating temperature arising from S-B law will not be at the surface, it will be at some height above the surface – and this height will change with atmospheric conditions, even if there is no change in solar forcing.

3.2.1 The importance of the GHE, according to the IPCC's reports

The basic claim in the IPCC reports, and of the EGGWH is that this entire difference (whether it is 33°C or 31.7°C) between the measured global average surface temperature and the effective S-B radiating temperature of an Earth is entirely due to the GHE of the atmosphere's GHG, which are principally H_2O and CO_2. The IPCC's reports say that GHG play a crucial and a life-giving role in the atmosphere; to sum up their findings:

The reason that the Earth is warm enough to sustain life is because of GHG in the atmosphere; temperatures would plunge dangerously low if there were no GHE to keep the heat in and the oceans would freeze over, life as it is now known would be impossible.

The basic assumption of the enhanced greenhouse hypothesis, is that it's ***the GHG and their natural balance*** that are responsible both for life on Earth and for the pleasant current temperatures which are experienced, and it follows that ***if this balance is upset by adding to them a dangerous rise in global temperatures will follow***.

The IPCC and advocates of the EGGWH say that humans have been responsible for increasing the atmospheric CO_2 concentration from 280ppm in 1750 to 400ppm in 2016, and have also been responsible for considerably increasing the atmospheric concentration of other GHG, such as CH_4, and that it is ***this interference in the natural balance of the climate system*** which has caused most of the global warming seen since 1950. In fact, the relative anthropogenic and natural climate forcing since 1750, as listed in AR5, (Figure 3.6) show that the IPCC reports are effectively saying that humans are responsible for 97.6% of all the warming seen since 1750. (Anthropogenic 2.29 W/m², natural 0.05 W/m².)

3.2.2 The big effect of albedo

Examining the figures that the IPCC uses to calculate the 33°C total for the GHE, show that current albedo is included. A question remains; can the present albedo of 29% be reasonably used in a calculation which involves the removal of the atmosphere? A large part of the 29% albedo of the Earth are its clouds, which cannot be there without the atmosphere, since they are a part of it. It also needs to be pointed out that they also consist of water, which is by far the strongest GHG (Schmidt et al., 2010) and would especially be a concern if CO_2 caused a positive feedback here.

A change in albedo of just 1% will result in a significant 0.9K change in global average surface temperatures – which is more than the measured rise in global temperatures since 1750. And 3.4 W/m² is also more than the overall forcing attributed to man on the climate system since 1750 of 2.29 W/m² (Team et al., 2014) (Figure 3.6). Land changes caused by man, which are affecting albedo take on more significance when this is realised. And when calculating the Earth's radiating temperature as a S-B black body, the subject of albedo has become contentious. The albedo of Earth would be much lower at around 12% if the atmosphere were removed, which would result in a warmer S-B result.

Figure 3.2 shows the relationship between albedo and probable surface temperatures on an airless Earth. If a figure of 12% is used for an airless Earth instead of the 29% figure that is associated with the atmosphere, then the above calculation yields a much warmer effective radiative temperature of 269.8 K (or -3.3°C). This would then point to a GHE (or more accurately, an atmospheric thermal enhancement) of only 17.5°C. This 'presence of atmosphere' effect has been detailed in the literature (Rancourt 2011).

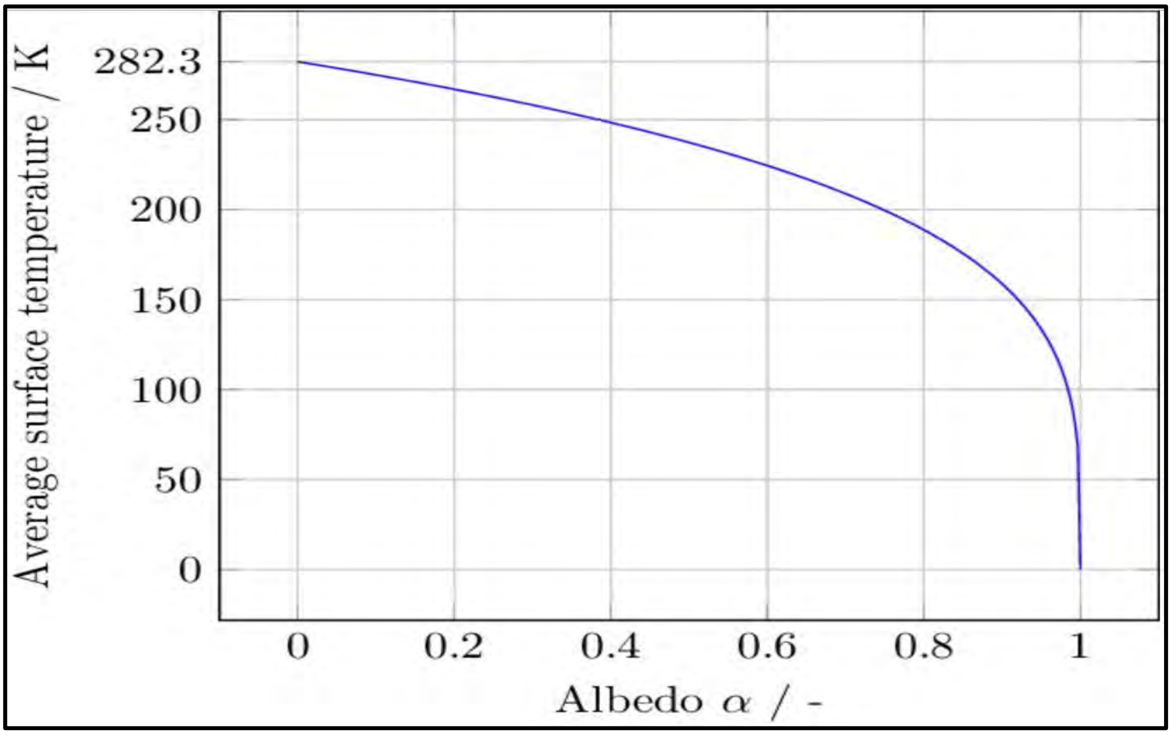


Figure 3.2 Albedo vs probable surface temperatures on an airless Earth

If this calculation is physically correct, and if the entire 'presence of atmosphere' is attributed to the GHG, this could reduce concern over anthropogenic greenhouse emissions, since it would effectively halve any current number for climate sensitivity; a figure which has already been declining steadily in the literature for decades (N Lewis & Crok, 2014). Yet in the IPCC's AR5, they still list the equilibrium climate sensitivity (ECS) as likely between 1.5°C and 4.5°C (Allen et al., 2014) (Team et al., 2014) a range which has hardly changed since the first IPCC report in 1990. Much of the reason for this IPCC stance emanates from the physics as presented in the Charney report (Charney et al., 1979).

Some recent estimates of ECS in the literature are very close to the low end, for example, 1.64°C (Nicholas Lewis & Curry, 2014) and some, at ~1.0°C are well below it (Bates, 2016) (Harde, 2014) (Cederlöf, 2014) (Abbot & Marohasy, 2017) (P. J. Michaels, Knappenberger, Frauenfeld, & Davis, 2002) (Monckton, Soon, Legates, & Briggs, 2015). Albedo changes are, as have been seen, very important in climate forcing estimates over time, and so a lot of attention has gone into measuring albedo changes using both satellites and earthshine measurements. As found in other climate data, such as that related to temperature, albedo from earthshine displays a large decadal variability (Pallé, Goode, & Montañés-Rodríguez, 2009), yet data from NASA's clouds and the Earth's radiant energy system (CERES), shows little change (Pallé et al., 2005).

3.2.3 What is climate sensitivity?

Climate sensitivity is the amount of global surface warming one should expect if the amount of atmospheric CO_2 (or a combination of GHG amounting to the equivalent in climate forcing) were to double. Consequently, if the entire GHE were found to be much lower than the above-calculated 31.7°C, then it would logically follow that each contributing portion to that total would individually (subject to feedbacks) be commensurately less. The individual effects of each gas is greatly complicated by the fact that they overlap one another in the radiative spectrum, however, the latest attribution estimates of the GHE (Schmidt et al., 2010) have apportioned the contribution of each gas (Table 3.1) as follows;

Table 3.1 Attribution of each GHG (Schmidt et al., 2010)

GHG	% Of the Total Greenhouse Effect
H_2O (water vapour and clouds)	75.0
CO_2	20.0
N_2O	1.3
CH_4	1.2
Others	2.5

In recent years, it has been found to be helpful to further divide climate sensitivity into two; equilibrium climate sensitivity (ECS) and transient climate response (TCR). ECS is the traditional meaning, which is the eventual warming – perhaps measured in hundreds of years – which is introduced to the climate system by a doubling of CO_2 or its equivalent from the so-called 'pre-industrial' level of 280ppm. According to the IPCC, the 'likely' range of ECS is 1.5°C to 4.5°C (Allen et al., 2014). TCR is the temperature change expected in 70 years' time which is introduced into the climate system by a doubling of CO_2 or its equivalent from the so-called 'pre-industrial' level of 280ppm. Thus, a projected temperature change is brought to within a person's life-span, and so is humanised.

According to the IPCC, the 'likely' range of TCR is 1°C to 2.5°C (Allen et al., 2014). These figures are relative to pre-industrial temperatures; measurements show that a 0.8°C rise from that level has already happened. Knowing the climate sensitivity would help with anthropogenic attribution in relation to a percentage of that measured rise, and going forward, assist with estimating the extent of future anthropogenically-driven temperature changes. This does not mean that global temperatures will rise in the future; since this is dependent on many other factors apart from climate sensitivity, not the least of which is the underlying natural variability.

3.2.4 What is 'modern global warming'?

Modern global warming can be defined as that warming trend which has occurred since global temperatures started to recover from the depths of the little ice age (LIA); from the data, this period is generally taken to have originated around 1690, and continues to the present. Accelerating industrialisation has been the hallmark of most of this period. In IPCC reports, the period of industrialisation is taken to have started in 1750; this is the date from which all radiative forcing on the climate system have been calculated. (Figure 3.6).

3.2.5 How much warming will be seen by 2100?

Climate sensitivity is one big factor here, and this is the domain of WGI in the IPCC; but there are other factors which influence just how much warming will occur by 2100. For instance, global population growth, the wealth growth rate of that population, type of governance and the energy mix, all of which relates to emission scenarios. These are the domain of WGII and WGIII whose job is to work on 'impacts, adaptation and vulnerability' and 'mitigation' respectively (Allen et al., 2014). The main property of climate sensitivity is that sensitivity is a ratio of the ratio of the logarithm of the change in flux to temperature change; if the ECS is considered, then it needs to be made clear that the more sensitive the climate system, the longer it will take for it to reach equilibrium, and this may be thousands of years. What has often been ignored in the hard-fought scientific discussion about climate sensitivity, is effects of the assumptions of WGII on temperature scenarios. Their work relies as much on climate modelling as WGI does – the projections they publish totally rely on the assumptions and inputs put into those models. These models are really where the projections of 2°C+ of warming by the mid-21st century and the higher values by 2100 come from. An incremental emissions change as listed by the IPCC is directly related to, and is thought to cause an incremental global temperature change (Team et al., 2014), however, this idea has not been borne out by the temperature trend over the last 20 years. The four main emissions scenarios used in WGII are determined by assessments of population, economics, governance and the state of technology (Figure 3.3).

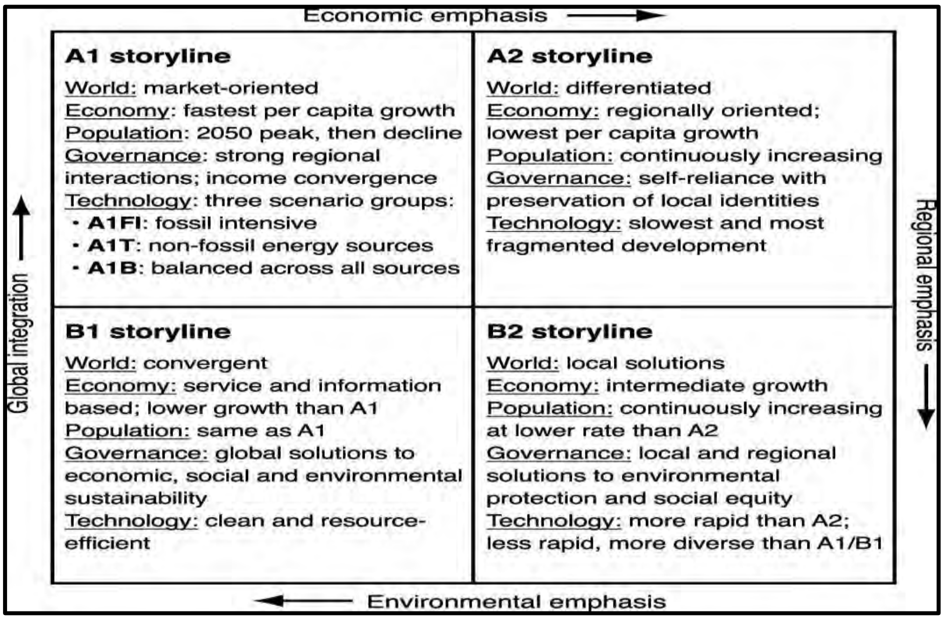


Figure 3.3 The four main scenarios in AR4 WGII (W. Spencer, 2007)

In AR5, the new scenarios are called 'representative 'concentration pathways' (RCPs) (Figure 3.4) and, these relate to the end of the 21st century (2081–2100), relative to 1986–2005. The difference between these and past scenarios is that RCP's are GHG concentration projections, and not emissions projections; they are named after GHG radiative forcing values relative to 1750 which are inputs into their respective CMIP-5 climate models (Weyant et al., 2009). However, the underlying assumptions/storylines, as depicted in Figure 3.3 from AR4 remain.

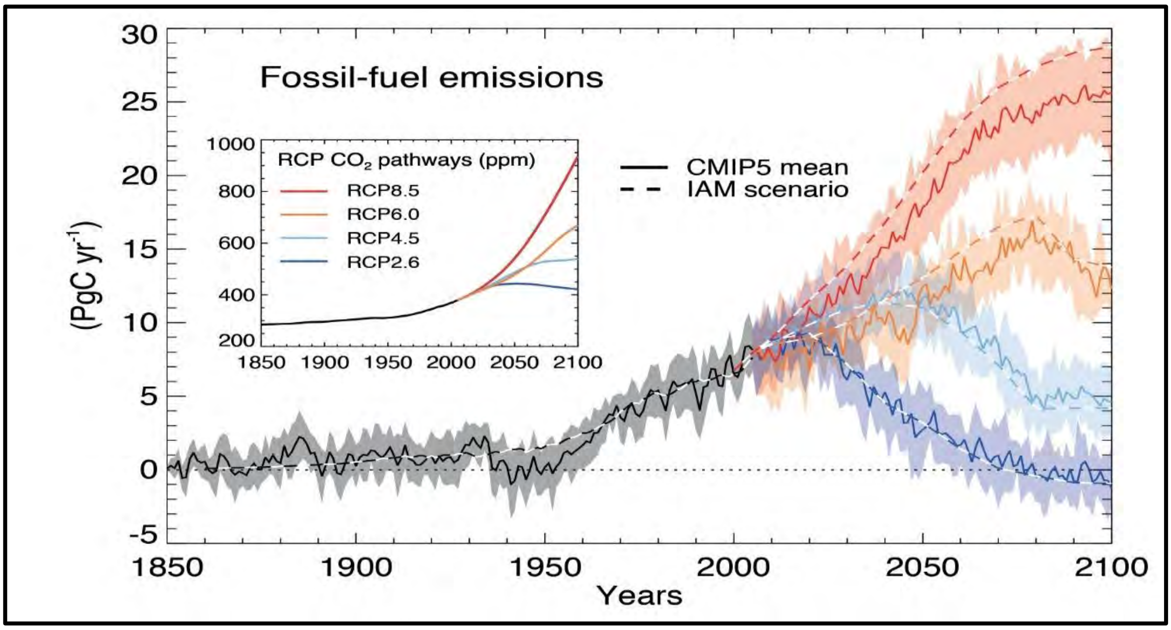


Figure 3.4 The four RCP's as displayed in AR5 (Team et al., 2014).

As mentioned, these scenarios (Figure 3.4) depend on the assumptions which are inputted into the models, about several factors, as depicted in Figure 3.3 such as;

- world GDP by 2100
- whether the world is ‘market-oriented’ or pursues ‘local’ solutions
- what the population rate is and what the final population number is in 2100
- what type of ‘governance’ is in place and
- technology advancement and the energy mix

The ‘worst’ scenario is shown in red - RCP 8.5 (similar to the A1 storyline in Figure 3.3) it details a world economy that is 25 times the GDP it is today, and even the poorest are better off than a typical westerner is today. This scenario assumes a global economic growth of 3% per year which is far higher than the 1.2% that has actually occurred since 1975 (Eclac) (2002). Also assumed is a large population increase, a combination which also seems extremely unlikely given what is known about the relationship between wealth, fertility and population growth (Myrskylä, Kohler, & Billari, 2009). All these scenarios also include higher per capita emissions than currently, this appears to be unlikely given that global per capita emissions have been stable with no growth since 1970; moreover, per capita emissions from most western countries, including the U.S.A., the U.K., and Australia have been falling since 1970 (Oak Ridge, 2017). The expectation under RCP8.5 is for a 4.9°C temperature rise above pre-industrial by 2100 (Alexander et al., 2013), there is a range of values for the other scenarios; RCP6.0 = 3.0°C, RCP4.5 = 2.4°C, RCP2.6 = 1.5°C (Moss et al., 2010). Under these scenarios, the 2100 population is expected to be somewhere between 6 and 15 billion, global GDP is expected to be somewhere between 70 and 620 billion dollars, energy consumption somewhere between 300 and 2,200 EJ and oil consumption is expected to be somewhere between 0 and 550 EJ (Van Vuuren et al., 2011), and global temperatures somewhere between +0.3°C and +8.5°C. Needless to say, there are a whole host of possible scenarios which could be modelled apart from the four completed here by the IPCC. It needs to be borne in mind that they are modelled scenarios which are based on a set of variables, not predictions, forecasts, or probable occurrences. None of them have been assigned a probability of occurrence by the IPCC.

3.3 The two competing hypotheses behind ‘modern global warming’

The debate over the main cause of the modern period of global warming rages both in and out of the scientific literature. In the scientific literature, there are two competing scientific hypotheses which seek to explain the main cause of the global warming seen since

1690, and more specifically, the warming seen since 1950. The 'mainstream' view, which is held by many prominent climate scientists, the IPCC and many other governmental and non-governmental scientific bodies, is that the warming has been mostly caused by man's emissions of greenhouses gases through the enhanced GHG effect. The 'sceptical' view, held by some climate scientists and by other scientists such as geophysicists, astrophysicists and many retired scientists, is basically the null hypothesis; which is that any warming or cooling has been and is now mostly natural. Support for the null hypothesis (or the recent period of global warming being mostly caused by natural variability) comes from scientists working across many specialist areas of science such as cycles in the Solar System, radiative physics, solar and planetary cycles, solar and cosmic ray physics, paleo-climatology and glaciology; new fields like cloud formation physics, cosmoclimatology and adiabatic auto-compression in planetary atmospheres are also being explored. Collectively, this represents what some have called the 'missing science' (Plimer, 2009), because it is missing from the 'gold standard' for climate reports, those of the IPCC. Much of this science is presented here, without apology, for this reason. Note that the differences between the two camps are based on percentages, and not on whether human activity affects global temperatures or whether global warming exists or not.

Climate science itself is a relatively new field of scientific inquiry; this being the case, there is no widely-accepted standard model which explains all the observed and all the known historical natural climate variability. It may be fairly said that the essence of the debate centres wholly and almost completely, around the climate sensitivity; both the ECS and the TCR. Logic dictates that before one can hope to estimate man's net effect on the climate system, one must first know the normal range of background natural variability, against which any such possible super-imposed anthropogenic effect may be measured. But, in the case of the IPCC, it's apparent that the natural variability in climate change was not assessed first. This ultimately gets back to two factors; the muddled definition of 'climate change' that the IPCC has, which is further complicated by different definitions that are in general use, even with the UN itself and the IPCC's mandate, which is obviously influenced by its definition of climate change. The IPCC's mandate was and is to find and report on human impacts on the climate system – not to determine the range of natural climate variability and then look for any possible super-imposed human effects. This mandate, and the fact that a much shorter summary for policymaker's report is issued and checked (and corrected) by bureaucrats from all signatory countries has led to the summary for policymakers differing from its much longer and more scientific peer-reviewed reports.

IPCC reports have had their critics. Dr Frederick Seitz, former president of the National Academy of Sciences and the American Physical society said about the second assessment report (SAR) 1995 report;

> "But this report is not what it appears to be - it is not the version that was approved by the contributing scientists listed on the title page. In my more than 60 years as a member of the American scientific community, including service as president of both the National Academy of Sciences and the American Physical Society, I have never witnessed a more disturbing corruption of the peer-review process than the events that led to this IPCC report" *(Wall Street Journal, 1996).*

3.3.1 The three common definitions of the term 'climate change'

1) Dictionary.com;

> *"A long-term change in the Earth's climate." (Dictionary.com 2017)*

2) UNFCCC;

> "Climate change" *means a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods." (UNFCCC, 1992)*

3) IPCC in AR4;

> *"Climate change in IPCC usage refers to a change in the state of the climate that can be identified (e.g. using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. It refers to any change in climate over time, whether due to natural variability or as a result of human activity."(Solomon, 2007)*

Further complication to the UNFCCC definition is that it is conceivable that climate change can be man-made without changing the composition of the atmosphere – for example if human activity changes the Earth's albedo. Of course, before man could have had any effect on the climate system, all climate change was natural, caused by natural variability, and according to the IPCC, this was prior to 1750. After 1750, the IPCC does seem to make a distinction in its reports between natural variability and changes in the climate caused by humans, both in the definition of climate change and in its listing of the various climate forcing's it says have affected the climate system since 1750; yet the term 'climate change' was re-defined in AR4 to include any change in the climate system, whether caused by man or nature. This muddies the waters when the IPCC, or their representatives speak about or write about attribution and climatic effects from the various drivers; the proponents of the EGGWH and the proponents of the null hypothesis often seem as if they are not even speaking the same language, and sometimes speak at cross-purposes.

The UNFCCC plots a different course to the IPCC. They separate the term 'natural variability' from the term 'climate change' entirely, so re-defining the latter term as henceforth only referring to anthropogenic effects on the climate system, and that is further refined to only include human effects on the atmosphere. In doing so they must of course then elevate the term 'natural variability' to be the only term which is to be used to refer to any underlying natural variability which takes place after 1750, and simultaneously re-define the term climate change so that it means only natural variability before 1750 and only anthropogenic effects on the atmosphere after 1750. Note that both the titles UNFCCC and the IPCC include the term 'climate change', so getting the definition right is obviously vitally important; yet more confusion arises when the IPCC's document 'Principles governing IPCC work' is read, it states;

> *"The role of the IPCC is to assess on a comprehensive, objective, open and transparent basis the scientific, technical and socio-economic information relevant to understanding the scientific basis of risk of human-induced climate change, its potential impacts and options for adaptation and mitigation." (IPCC, 1998)*

This appears to be the IPCC considering the impacts of man-made climate change and what can be done about those impacts before any man-made climate change has been found or quantified. The main practical difficulty, though, is how can any possible anthropogenic effect on the climate be assessed, if the extent and the expected range of natural variability based on *its* historical cycles and *its* historical forcing's has not been defined first?

A further complication which adds to the general confusion about the precise meaning of the common terms used in discussions, is that the term 'global warming' also means different things to different people or groups (Lindzen, 1996). To some, it means the observed global near-surface temperature change since 1950, to others, since 1750, to yet others it means the man-made part of the former, or the latter. Some include natural variability in the term and others do not, as is the case with the term climate change.

3.4 The enhanced greenhouse gas warming hypothesis

In this hypothesis, the accelerating industrialisation since 1750, and its associated GHG emissions has generally been assumed to be the causative factor of the warming; especially in the period 1975-2000 when global warming and GHG emissions seemed to move together in a cause and effect relationship. Specifically, in the IPCC's two latest reports the AR4 and AR5, delivered in 2007 and 2014 (Team et al., 2014) there was a growing confidence (90% grew to 95%) that 'most' of the observed global warming since 1950 has been caused by the growing anthropogenic GHG emissions; these being principally CO_2 and CH_4. This conclusion is based on atmospheric modelling, on correlation and on radiative forcing arguments; the best estimate being in fact that almost all the observed warming since 1950 has had an anthropogenic cause (Allen et al., 2014).

The enhanced CO_2 warming hypothesis states that the mild initial GHG warming from CO_2 is approximately 1.1°C per CO_2-e doubling of concentration (from radiative forcing arguments) (Schneider, Kirtman, & Lindzen, 1999) is increased through an amplifying mechanism. That is; by an overall positive feedback from summing the various feedbacks in the climate system. Most of this positive feedback is thought to have come from the most powerful GHG, water vapour. The enhanced CO_2 hypothesis states in effect that; CO_2 creates some warming of the climate system, this causes more evaporation to occur from the oceans, this extra GHG (water vapour) in the troposphere causes even more warming of the climate system (Ramanathan & Vogelmann, 1997). In this way, the initial mild warming effect of CO_2 is predicted to approximately triple in size (Philipona, Dürr, Ohmura, & Ruckstuhl, 2005) through this positive water vapour feedback mechanism.

This tripling estimate was arrived at by studies of paleo-climates and the relationship in them between proxy CO_2 concentrations and proxy temperature series (von Deimling, Held, Ganopolski, & Rahmstorf, 2006). The eventual surface global warming to be expected from a CO_2-e doubling in the climate system, is the ECS. The total warming effect can only occur when the climate system finally equilibrates from the initial forcing, which may take centuries to millennia. To calculate the ECS, there is a need to know the sum of all the feedbacks as follows;

$$\Sigma t = fw + flr + fia + fc \quad (4)$$

Σf = total of all feedbacks
fw = water vapour feedback
flr = lapse rate feedback
fia = ice albedo feedback
fc = cloud feedback

Typical figures for these may be (Dessler & Sherwood, 2000);

$$\Sigma f = 0.55 + (-0.3) + 0.1 + 0.15$$
$$\Sigma f = 0.5$$

Then the ECS can be calculated;

$$\Delta Tf = \frac{\Delta Ti}{(1-\Sigma f)} \quad (5)$$

Tf = final temperature (ECS)
Ti = initial temperature
Σf = total of all feedbacks
Δ = change in

If the initial forcing from a doubling of CO_2 is 1.1°C, then;

$$\Delta Tf = \frac{1.1}{(1-0.5)}$$

$$ECS = 2.2°C$$

(It will be noted that if the total feedbacks = 1 then ECS = ∞)

A change in one number can make a large difference to the ECS. For example, a figure for fc (the cloud feedback for high cirrus clouds, or 'ice') has been reported at -1.9 (R. W. Spencer & Braswell, 2010). Other things being equal, this one simple change results in a much lower ECS of 0.43°C; this is so low that in practice it would be hard to measure in the real atmosphere, and would be of no immediate concern. This example does highlight one of the main sources of uncertainty in accurately calculating the ECS; cloud feedback. Other numbers in the literature for fc are +0.4 (Schneider et al., 1999) and -1.1 (Lindzen et al., 2001).

3.4.1 ECS verses TCR

More sensitive climates take longer to reach their stabilising temperature than less sensitive ones; for example, a very high ECS of 6°C will take thousands of years to equilibrate, but a very low ECS of 1°C will be equilibrated in 2 years. Recent papers appear to have better constrained the more relevant TCR (Myhre et al., 2015). The recent interest in TCR, with its more human response time-frame of 70 years, means that if the climate system is examined over this period, a high and a very high climate sensitivity will not be able to be distinguished, since their response during this time period will be very similar. However, a 70-year period will allow a low and a very low climate sensitivity to be distinguished, because both reach equilibrium temperature quite fast. The difference in practice between ECS and TCR responses, to very low sensitivity climates such as ~1°C or lower, is marginal.

3.4.2 Support for the existence of GHG warming

3.4.2.1 Detection of the forcing caused by CO_2 - what does it mean?

A recent paper has detected a trend in climate forcing, and related it to an atmospheric change in CO_2 levels (Feldman et al., 2015). Satellite measurements were taken between 2000 and 2010 and they detected an increase in opacity at the wavelengths absorbed by CO_2, of 0.2 $W/m^2 \pm 0.06$ W/m^2 per decade. During the same period, CO_2 concentrations rose by 22ppm, at a mean annual rate of 2.1ppm. This is one of the few pieces of empirical evidence that exists for the reality of the changing greenhouse effect.

As will be seen from a calculation using the S-B black body law, a forcing of 2.29 W/m^2 is equal to no more than 0.59°C of global warming (ex - feedbacks). So, it can also be said that the measured 0.2 W/m^2 per decade of forcing on the climate system by the increasing atmospheric CO_2 concentration, should on this ratio, amount to an underlying warming of 0.05°C per decade. And, remembering that the ongoing forcing on the climate system reduces with each incremental step (Figure 3.40) then it can be said that this underlying warming amount is unlikely to increase, even if the net emission rate of CO_2 increases due to human activity. An underlying warming rate of 0.05°C per decade is a rate of 0.5°C per century – or a 0.4°C rise above current levels by 2100; a figure unlikely to be of concern to anyone and is so small it may not even be discernible among natural variability, unless it persists.

3.4.2.2 The late 20th century warming and the reduction in solar activity

Many papers in the climate journals simply cite the late 20th century rise in atmospheric CO_2, the simultaneous global warming and the fall-off in solar activity as being their strongest evidence for an anthropogenic cause for global warming. These and other factors are then seen as 'fingerprints' of human activity on the climate system, which confirm their hypothesis (Gabriele Hegerl, Zwiers, & Tebaldi, 2011). Several different emissions scenarios are then projected far into the future using various climate modelling programs, like CMIP-5.

3.4.3 The stated position of most scientific bodies

Most of the planet's top scientific bodies mirror the conclusions which are in the IPCC's reports. California's governor's office lists 200 scientific bodies who, they say;

> *"Hold the position that climate change has been caused by human action". (California, 2017).*

This appears to be claiming that climate change has *already* been caused by human actions. The learned bodies who state their agreement with the IPCC's consensus position include the Royal Society UK, the National Academy of Sciences USA and the Australian Academy of Science.

3.4.3.1 Fingerprints of global warming arguments

A good overview of the EGGWH hypothesis comes from Sloan and Wolfendale (Sloan & Wolfendale, 2013). Much published work in the field of climate is comparing measured climate change against modelled simulations and emissions scenarios; these are then often extrapolated into the future to arrive at projected climate states. However, clearly the most important work done in the field of climate is that relating to attribution. Attribution says what the cause of the measured climate change is, or what the cause of the global warming which is under investigation is. Attribution – specifically involving the so-called 'fingerprints of global warming' (Figure 3.5) (Gabriele Hegerl et al., 2011) is what led the IPCC to the assertion in AR4 that;

> *"Most of the observed increase in global average temperatures since the mid-20th century is very likely (>90% probability) due to the observed increase in anthropogenic GHG concentrations."*
>
> (G Hegerl et al., 2007)

One of the fingerprints of man on the climate system, is said to be the 'unusual' level of warming now being experienced (Mann, Bradley, & Hughes, 1998) (Hoegh-Guldberg & Bruno, 2010). That the current warming is 'unusual' has been strongly disputed by sceptics of the enhanced GHG hypothesis (Horst-Joachim Lüdecke, 2011) (Scafetta, 2010) (H-J Lüdecke, Weiss, & Hempelmann, 2015). Some of these sceptics are so-called 'luke-warmers' who believe that there is some effect from anthropogenic CO_2, but that it is not dangerous and in fact may be net beneficial. Other sceptics doubt the strength of the greenhouse effect itself; but all sceptics think that natural variability still predominates over the effects of man-made greenhouse gases in today's climate.

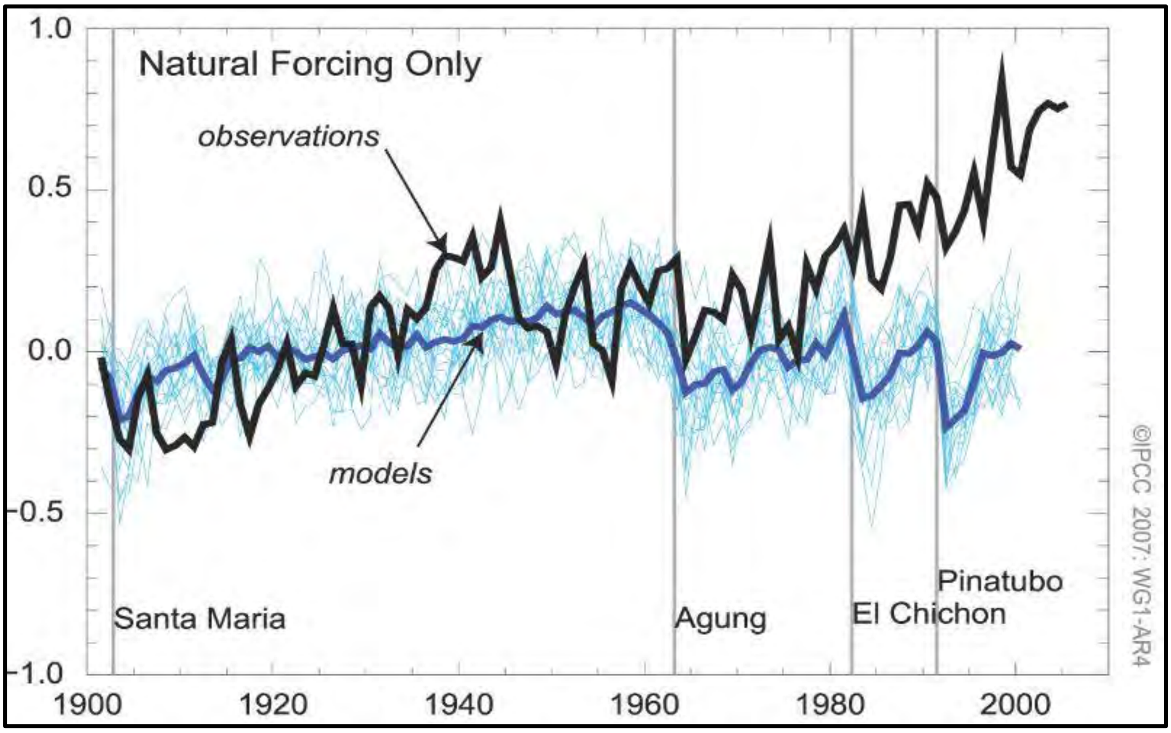


Figure 3.5 Without human emissions, models do not match reality (Solomon, 2007)

3.4.4 Radiative arguments lead directly to 'The Anthropocene'

The IPCC's 2014 AR5 Summary for Policymakers (Team et al., 2014) report states that in terms of their GHG effect, anthropogenic GHG 1750-2011 had a total forcing associated with their release of 2.29 W/m² (Figure 3.6). In the same document, the total natural forcing during the same period (which is just the estimated changes in total solar irradiance, henceforth TSI) was just 0.05 W/m². The IPCC therefore say that the human effects on the climate system were (2.29/0.05) = ***45.8 times*** all the natural effects on the climate system, over the last 261 years. And that, of the anthropogenic GHG, CO_2 was responsible for (1.68/2.29) 73% of the combined forcing, and (1.68 / (2.29+0.05)) 72% of the total climate drivers affecting the climate system since 1750. Therefore, the current era has been given the name 'The Anthropocene' since on these figures, man is responsible for 97.9% of all the forcing's which are currently driving climate change.

If these figures are right, it can be concluded - as many scientists, and the U.S. environmental protection authority (EPA) have - that it is correct to call anthropogenic CO_2 'pollution', and by extension any other anthropogenic gases which contain carbon 'pollution' as well, and collectively to refer to them all as 'carbon pollution'. These figures also give an insight into just why CO_2 is called ‘the climate driver’. In many centres of learning across the developed world, it is now the belief that the atmospheric concentration of CO_2 in the atmosphere has been un-naturally raised by human activity, and this has driven the climate system over the last 50 years.

3.4.5 How much warming are humans responsible for to date?

Given that the above belief is true, can this be calculated? How much warming have anthropogenic emissions been responsible for since industrialisation started? If the AR5 radiative forcing figures are used along with the S-B black body law, then an approximation may be arrived at. Here, the net anthropogenic radiative forcing from 1750 to 2011 of 2.29 W/m² is to be taken from the AR5 (Figure 3.6) and converted into a temperature equivalent;

From Stefan-Boltzmann $\quad F = \delta T^4 \quad (6)$

F = energy flux in Joules per m^2/s^{-1}

$\delta = 5.67 \times 10^{-8}$ W/m² K^{-4}

T = temperature in Kelvin

Surface pre-industrial forcing was 242 W/m² = 242 J/ m^2/s^{-1}

And since the anthropogenic net forcing is: 2.29 W/m² = 2.29 J/ m^2/s^{-1}

Then: $\quad T^4 = F/\delta \rightarrow \sqrt[4]{T^4} = \sqrt[4]{(F/\delta)} \quad (7)$

$$T = \sqrt[4]{(F/\delta)}$$

$$T_1 = \sqrt[4]{(242/5.67 \times 10^{-8})}$$
$$T_1 = \sqrt[4]{(242 \times 10^{8}/5.67)}$$
$$T_1 = 10^2 \times \sqrt[4]{42.68}$$
$$T_1 = 10^2 \times 2.5559$$
$$T_1 = 255.59K$$

$$T_2 = \sqrt[4]{(244.29/5.67 \times 10^{-8})}$$
$$T_2 = \sqrt[4]{(244.29 \times 10^{8}/5.67)}$$
$$T_2 = 10^2 \times \sqrt[4]{43.08}$$
$$T_2 = 10^2 \times 2.5619$$
$$T_2 = 256.19K$$
$$T_2 - T_1 = 0.59K$$

A net anthropogenic forcing of +2.29 W/m² = ΔT of +0.59K. This is seen as a maximum for the troposphere (ex-feedbacks). These figures isolate this forcing and do not allow for any atmospheric warming effects, the result of this lowers T_1 and may over-estimate the warming from this forcing, since each additional increment of forcing has less warming effect as temperatures rise, due to the fourth power term in the S-B formula.

Alternatively, if the Planck sensitivity from AR5 is used (0.31K per W/m²) is used instead, the warming before feedbacks would be;

$$2.29 \times 0.31 = 0.71K$$

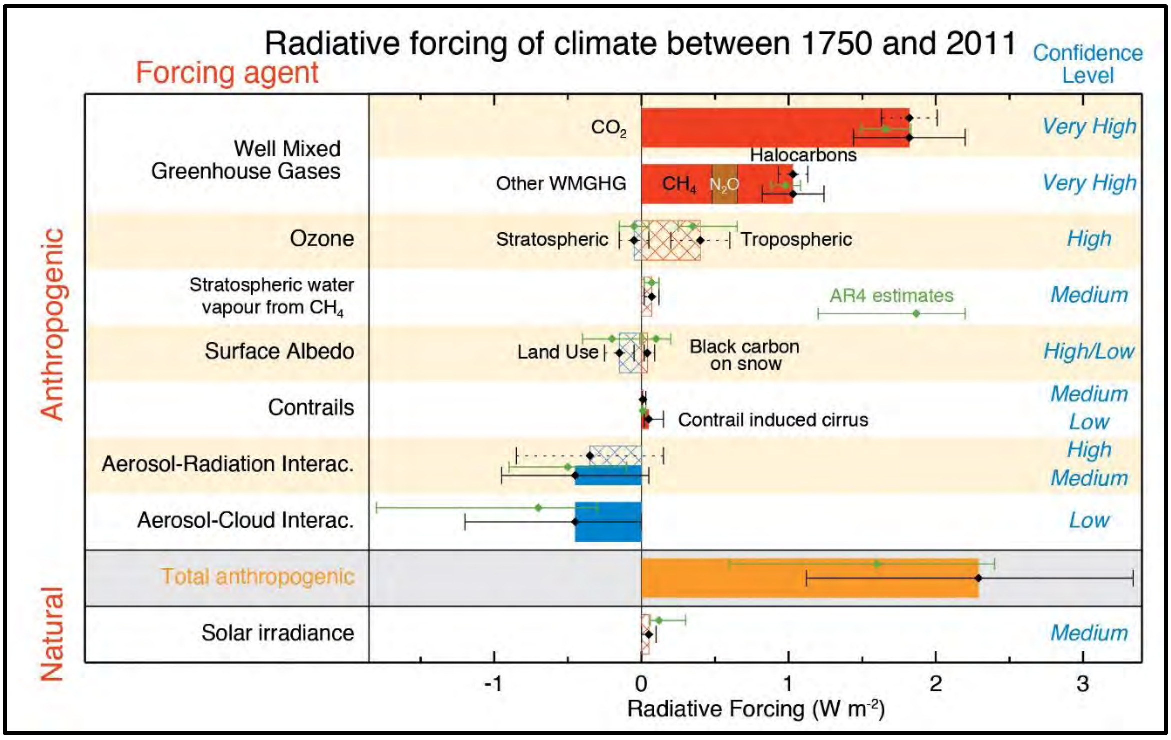


Figure 3.6 Radiative forcing 1750 - 2011 as detailed in AR5 (Team et al., 2014).

3.4.5.1 *The faint young Sun paradox*

Billions of years ago, when the Solar System was young, astronomers say that because of stellar evolution theory the Sun must have emitted about 30% less energy than it does now (Hart, 1979); yet the Earth somehow did not become a frozen ball of ice (Ueno et al., 2009). The only logical explanation for this according to proponents of the enhanced GHE, is the level of CO_2 and other GHG in the atmosphere at the time, which kept sufficient heat in the troposphere to keep the oceans liquid, (Foukal, Fröhlich, Spruit, & Wigley, 2006; Jenkins, 2000; J. Kiehl & Dickinson, 1987). However, as will be seen in the section on auto-compression, if the atmosphere had a greater surface pressure than 1 bar billions of years ago, then perhaps the paradox could be solved (Sorokhtin, Chilingar, Khilyuk, & Gorfunkel, 2007). It has been suggested that the Earth's atmosphere has generally been >1 bar, and indeed reached up to 3-5 bar in the period 2.5 – 3.5Gya (L. F. Khilyuk & Chilingar, 2006), this pressure 'spike' being mostly due to outgassing of CO_2.

3.4.5.2 *What is the evidence for recent 'unusual' warming?*

The 'hockey stick' graph controversy; part of the evidence that has been presented to support the notion that the current period of global warming has been higher and faster than previous periods of global warming, is contained in papers which relate to paleoreconstructions, often those which cover the last 500 - 1500 years or so of the climate record. One such reconstruction of the climate record (Mann et al., 1998) covered the period 1400AD – 2000AD in the Northern Hemisphere; it was later extended back to 1000AD (Figure 3.7) and subsequently published in the IPCC's third assessment report (Griggs & Noguer, 2002), but was dropped in the later IPCC reports.

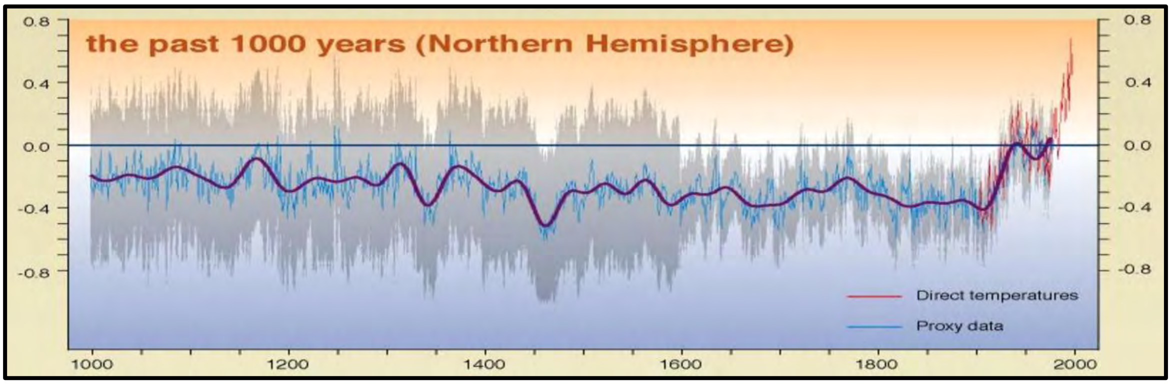


Figure 3.7 The hockey stick, published in the IPCC TAR (Griggs & Noguer, 2002).

This became known as the hockey stick graph; even though not a global reconstruction, it does correlate quite well with the growth in anthropogenic GHG emissions. With this graph, the authors do imply a causation for the temperature record; the rise in atmospheric CO_2. However, other researchers find no correlation (Munshi, 2016) and the reconstruction itself has come under harsh criticism in the literature (McIntyre & McKitrick, 2004). The IPCC dropped the graph from its next climate report, the AR4.

3.4.5.3 Australia's climate change record

In its state of the climate report, (CSIRO, 2016) Australia's temperature has warmed by 1°C since 1910, which is a significant ~0.10°C per decade (Figure 3.8).

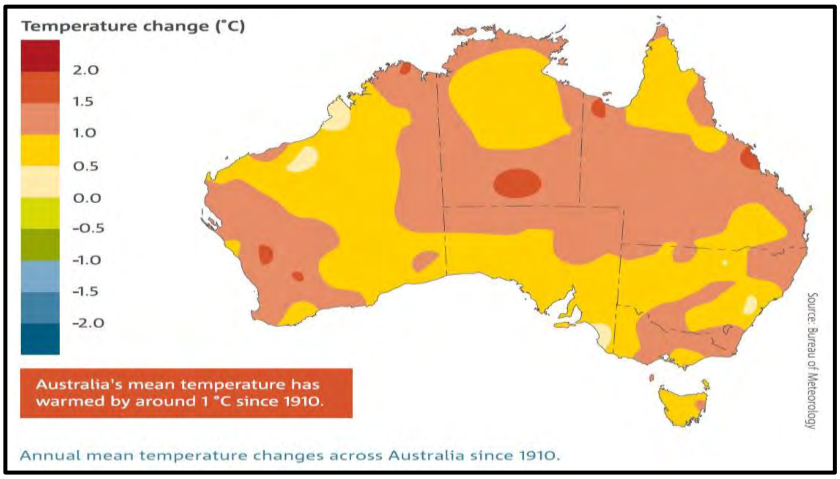


Figure 3.8 State of the climate report (CSIRO, 2016)

However, using 1910 as a starting date may be problematic, since as shown in Figure 3.9, this is a low in the temperature record because of the 61-year Yoshimura climate cycle (Yoshimura, 1979). Global temperatures are known to have fallen 1880 – 1910 (NCDC/NOAA temp.data) (Figure 3.9) by approximately 0.4°C, and although the record is sparse at that time in Australia, it is known that there was a similar fall in Australia's temperature record during these years. Taking this into account reduces the rate of rise to just 0.04°C per decade.

The main global surface temperature datasets have come under considerable criticism recently for not adjusting for heat island effects as cities expand past temperature recording stations, for making apparently unnecessary adjustments to original records, and for homogenising data records. This has happened in Australia, where some homogenisation practices to records have been questioned (Jennifer Marohasy & Abbot, 2015), and other adjustments, for example to the Rutherglen record (Jennifer Marohasy). The raw data at Rutherglen show a cooling trend 1913-2014 of -0.3°C/century, but the bureau of meteorology's (BOM) adjusted official data, displays a warming trend of +1.6°C/century. The main concern here is that Rutherglen forms part of the ACORN-SAT data, which feeds into global datasets. Another concern is that the BOM use 1910 as a starting point to measure the current period of global warming, which is a known low in the record, instead of 1880, where many station records actually start. There also appear to be problems with the BOM's wider dataset (JJ Marohasy & Abbot, 2016).

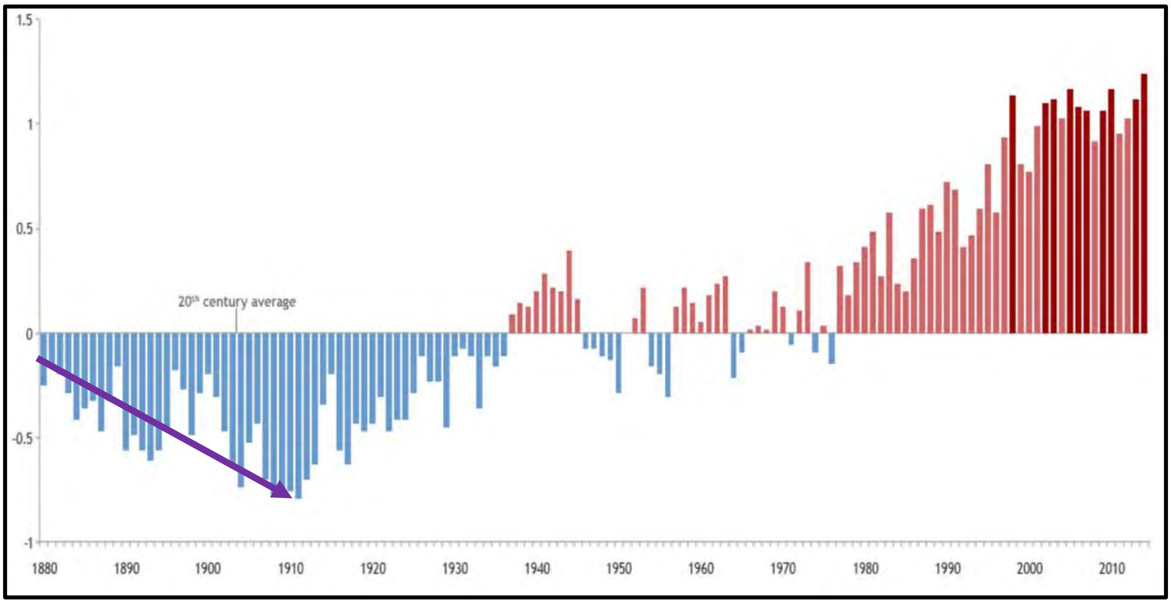


Figure 3.9 Global temperatures show a fall 1880-1910 (NCDC/NOAA temp.data)

3.4.5.4 The hothouse and the icehouse Earth

Similar arguments apply to later periods, when the Earth went through severe climatic changes, variously described as 'hothouse' Earth and 'icehouse' Earth. The hothouse periods are often claimed to be the result of excess atmospheric CO_2 (Jenkyns, 2003) (Wilcox, 1975).

3.4.5.5 The residence time of CO_2

Anthropogenic emissions of CO_2 are ~38Gt/yr which is ~5% of the natural emissions, which are ~770Gt/yr. The anthropogenic emissions effectively divide into three parts; 30% being absorbed by the oceans, 30% is absorbed by biota and the remaining 40% remaining in the atmosphere (Figure 3.10).

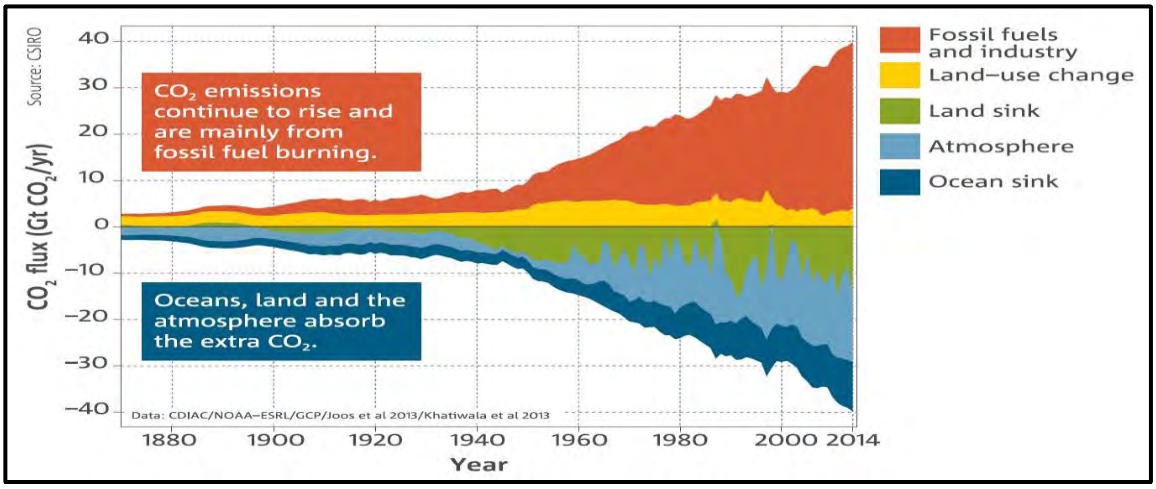


Figure 3.10 CO_2 divides; 30% to land/oceans 40% to atmosphere (CSIRO, 2016)

How long the atmospheric portion will remain there has been a contentious issue in the literature. Chapter six of WG1 (Team et al., 2014) in AR5 states;

"The removal of human-emitted CO_2 from the atmosphere will take a ***few hundred thousand years****....this makes climate change caused by elevated CO_2 irreversible on human time-scales". (my emphasis)*
(Team et al., 2014)

But there is considerable material in the literature, which conclude that the residence time of anthropogenic CO_2 is only around 5 years (Lepori, Bussolino, Matteoli, & Spanedda) (Segalstad, 1998) (Quirk, 2009) (Harde, 2017). The logic which is used, is that the atmosphere currently contains 800 GtC and some 150 GtC goes in and out of it each year. This gives a residence time of a typical CO_2 molecule of 800/150 = 5.3 years. Although this may be true, the argument put forward in AR5 (Ciais et al., 2014) is that the natural balance of sources and sinks has been thrown out of balance by man's rapidly rising CO_2 emissions, causing a net annual surplus which is accumulating in the atmosphere. The AR5 in fact claims that **all** the rise in atmospheric CO_2 since industrialisation in 1750 (now totalling ~125ppm) is attributable to man. The CO_2 pre-industrial level is stated to be *'278ppm'* and *'increased by 40% to 390ppm by 2011'*. AR5 further states that it is *"unequivocal"* that the current CO_2 level;

"..exceeds any level measured for at least 800,000 years, the period covered by the ice cores" *(Ciais et al., 2014).*

All these claims have been disputed in the literature. For example, Harde (Harde, 2017) argues that just 17ppm of the present atmospheric concentration of CO_2 is anthropogenic; Lepori say it's 31ppm (Lepori et al.) these figures are far from the 'mainstream' or the IPCC's current claim of 120+ppm being anthropogenic (Allen et al., 2014). Essenhigh (Essenhigh, 2009) argues that there is a short CO_2 residence time, and this means that only a small amount of the current global warming can be attributed to man, even if the IPCC's median climate sensitivity is taken to be correct.

3.4.5.6 CO_2 levels 'higher than they have been for 800,000 years'

The ice core records for CO_2 from Vostok in the Antarctic (Jouzel et al., 2007) and the EPICA Dome C (Wolff et al., 2010) (Figure 3.11) go back 800ky, and show a range of 180ppm – 300ppm. This had led to the widely-publicised claim that present atmospheric CO_2 levels, currently around 400ppm, are;

'higher than they have been for at least 800,000 years'.
(Lüthi et al., 2008)

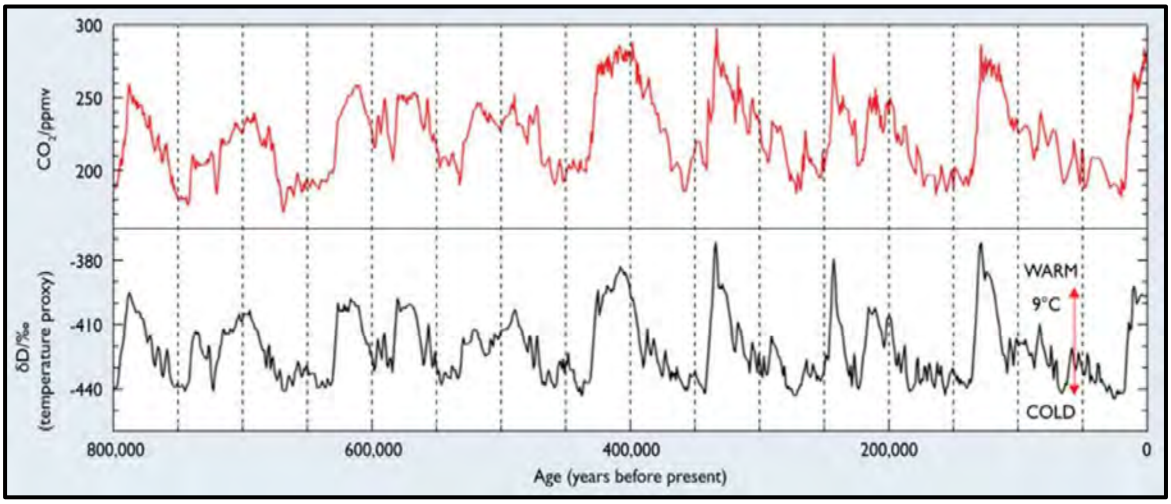


Figure 3.11 EPICA Dome C ice core CO_2 and temp proxy ^{18}O (Wolff et al., 2010)

3.4.5.7 Isotopes – do they prove an origin for the extra CO_2?

One of the 'fingerprints' of man-made global warming is said to be the change in atmospheric carbon isotopic ratios. The carbon isotope ratio in natural carbon is;

^{12}C	98.9%
^{13}C	1.1%
^{14}C	very low

Different pools of carbon display different ratios and these are called 'isotopic fingerprints'. Pools with more ^{13}C are called 'heavy' and those with less ^{13}C 'light'. Plants tend to prefer ^{12}C and tend to use more of it; probably because this isotope is lighter, and goes into the stomata easier. This means that when the plants die and decay – or turn into fossil fuels, their pool of carbon is 'light'. But the oceans seem to treat both isotopes equally, and so the atmosphere and the oceans tend to have similar ratios of the isotopes.
There is also another isotope of carbon, ^{14}C. This isotope is very rare, perhaps only 1 atom per trillion in the atmosphere, and because its half-life is just 5,700 years, no ^{14}C is found in fossil fuels. A little ^{14}C is always produced in the stratosphere by the action of cosmic rays, and much more when there is strong solar activity, such as in 5,480 BC (Miyake et al., 2017) which makes this isotope a solar activity proxy – a cosmogenic nuclide, created by cosmic ray spallation. Because of its half-life, this isotope is useful for dating human settlements; this length of half-life also makes ^{14}C an excellent solar activity proxy, and this is amply demonstrated in Figures 3.22 3.23 and 3.66. Unfortunately, in recent decades, this proxy has become contaminated by atmospheric nuclear tests, performed in the 1950's and 60's, as these also produce ^{14}C; because of this it's value in estimating recent atmospheric anthropogenic CO_2 content has diminished. However, there is another isotope which can be used for this purpose, ^{13}C. This is a stable isotope of carbon, and because it is slightly heavier than ^{12}C, it is not as taken up by plant life as much because it does not fit so easily into the stomata; also of note, is that stomata size varies with atmospheric CO_2 concentrations. This property has proven to be useful, since it means that the size of plant stomata then become a proxy for atmospheric CO_2 concentrations.

3.4.5.8 How much anthropogenic CO_2 stays in the atmosphere?

The relationship between these isotopes, the carbon cycle and the radiative properties of atmospheric CO_2 are explored by atmospheric physicist Murray Salby in his seminal book 'Physics of the Atmosphere and Climate' (Salby, 2012). Professor Salby, the former climate chair at Macquarie University in Sydney Australia, has been able to do excellent work on the carbon cycle and the influence of anthropogenic CO_2 emissions on the climate. Salby finds an excellent correlation between the net emission rate of CO_2 and global temperatures (Figure 3.12). Salby's work indicates that not more than 2.6% of the observed increase in atmospheric CO_2 can be anthropogenic.

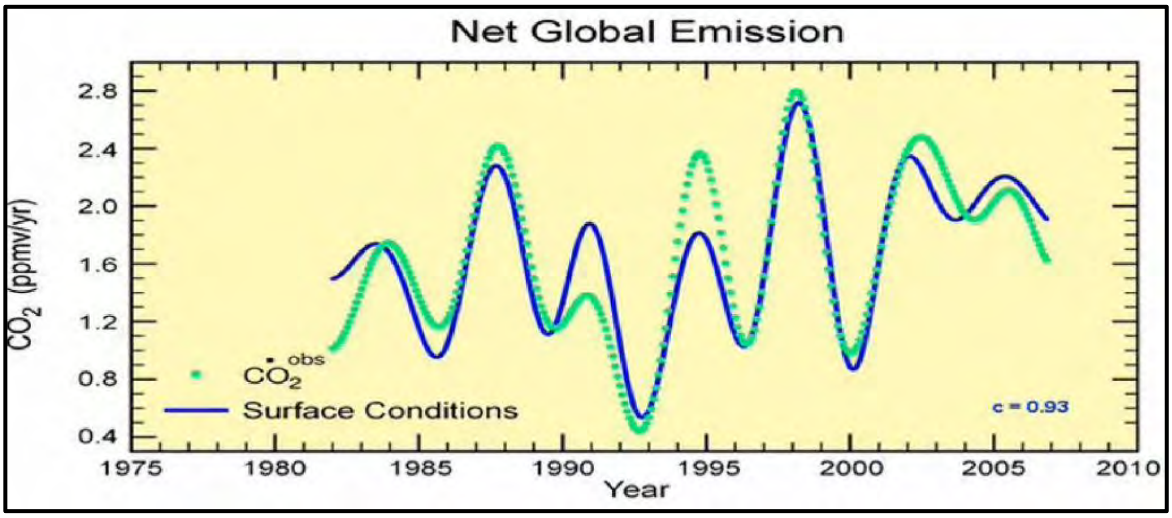


Figure 3.12 CO_2 Emission & surface conditions; c = 0.93 (University College, 2016)

The changes seen in the CO_2 record are highly correlated (corr. = 0.93) with surface conditions, (which are principally temperature). Salby has strong arguments (University College, 2016) to support the notion that not all of the observed CO_2 rise since 1750 can be attributed to human emissions, in fact calculating that very little of the increase is anthropogenic. The reasoning is that firstly, anthropogenic CO_2 emissions are just 4% of total CO_2 emissions, and that net emission rates are observed to remain unchanged, even though human emission rates have doubled since the year 2002 due to the rapid industrialisation of China. Net emission rates of CO_2 were found to be related to surface conditions and not to human CO_2 emission rates.

Atmospheric levels of ^{13}C are much higher than the levels in fossil fuels, and just as the atmospheric ^{14}C level is decreasing so is atmospheric ^{13}C decreasing – but at a much slower rate (Damon & Sonett, 1991). It is known that ^{14}C is decreasing because it's being diluted by fossil fuel emissions, because it's decaying, and because it's been taken up by carbon sinks. But ^{13}C is a stable isotope, and it is decreasing for just two reasons; because of sinks and because of fossil fuel dilution. To calculate how much of the fossil fuel emissions remain in the atmosphere, the following method can be used (Le Quéré et al., 2012);

$$((V_e/V_e+V_a)*\delta 13_e) +((V_a/V_e+V_a)*\delta 13_a) = V_{na}*\delta 13n_a \quad (8)$$

Where:

V_e = Volume of Emissions
V_a = Volume of Atmosphere
V_{na} = New Volume of Atmosphere
$\delta 13_e$ = δ C13/C12 of Emissions
$\delta 13_a$ = δ C13/C12 of Atmosphere
$\delta 13_{na}$ = New δ C13/C12 of Atmosphere

In the period 1979 – 2008 the ratio δ declined from -7.6 to -8.2. This is consistent with just 14% of the fossil fuel emissions remaining in the atmosphere until today, which is equivalent to ~16ppm. This figure is close that found by others (Harde, 2017).

3.5 The null hypothesis and the 'missing science'

The null hypothesis, or the default position in the field of climate, is that the current period of global warming, or climate change that is now being experienced is almost all natural variability, and so in effect says that there is little relationship between human activity and the observed changes. The possibility that the null hypothesis is the correct one, has never been seriously considered by the UN, the UNFCCC or the IPCC. In the normal course of a scientific investigation, the null hypothesis is generally assumed to be the correct one unless it must be rejected by the observed data. Most scientists would use the 'hypothesis testing' approach, used by Jerzy Neyman (Neyman, 1937), where data within a certain statistical error rate is used to invalidate the null hypothesis, and possibly to validate an alternative hypothesis. Figure 3.5 is an example of this hypothesis testing, where the known global temperature curve is plotted against a modelled curve of the null hypothesis, and they are observed to not be a match within the allowed statistical error. Naturally, this result is only valid in this case, if the curve generated from your climate model is an accurate representation of natural variability. Some scientists criticise the climate models on this basis, because they do not model clouds or volcano's correctly, neither do they include any of the many known climate cycles (except perhaps the Schwabe) which are noted in Table 3.4. The null hypothesis is presently composed of, and is supported by three parts, each of which will need to be assessed individually;

i. Cosmoclimatology
ii. Adiabatic auto-compression
iii. Astronomically induced climate cycles

3.5.1 The null hypothesis part one - cosmoclimatology

The argument put forward by proponents of the EGGWH hypothesis is that changes in TSI are only 0.01% during a Schwabe solar cycle (Foukal et al., 2006) and that the change in TSI is too small to have caused the 0.8°C of global warming measured since 1750. The reply by proponents of the null hypothesis is that;

- this temperature rise is historically not unusual
- the TSI range is greater than that which is generally assumed
- amplifying mechanisms exist for solar activity changes, including for TSI through the cosmic ray-cloud link
- the Sun has other climate forcing agents acting for it, apart from just TSI
- the GHG effect in the troposphere may be smaller than is thought, due to a tropospheric temperature gradient caused by auto-compression
- many other climate cycles exist apart from the one quantified by the IPCC
- recent natural variability is much greater than is shown by tree ring proxies

The natural, default or null hypotheses generally includes the cosmic ray and cloud hypothesis, called 'cosmoclimatology' as discovered and named by Professor Henrik Svensmark. It involves an amplifying mechanism, which acts through a solar activity-cosmic ray to low cloud link on short time-scales and through a GCR to low cloud link on long time-scales; the surface temperature is therefore altered by albedo changes. Cosmoclimatology says that the flux of cosmic rays of the right energies, (Svensmark, 2007b) those which are powerful enough to create a cascade of muons and other relativistic particles that can reach the Earth's lower atmosphere, is moderated by the strength of the solar magnetic field and the solar wind (Svensmark & Friis-Christensen, 1997). And the quantity and reflective properties of low clouds are changed by these cosmic rays, through the resultant muon shower's ability to seed these clouds or to change their properties (i.e. their area or the reflectivity / whiteness) by generating aerosols or cloud condensation nuclei (henceforth CCN's). The properties of low cloud are changed by the production of CCN's of a smaller size than those which would otherwise naturally occur. The Earth's magnetic field plays a much smaller role, it appears to be only capable of affecting 3% of the average cosmic ray flux (henceforth CRF) (Svensmark, 2007a). This hypothesis puts clouds at the very centre of climate changes; in cosmoclimatology, clouds are not the small bit players that are unsuccessfully modelled and are just 'there' as they are in EGGWH; they actually determine surface temperatures. Prominent scientists who are proponents of this hypothesis are Henrik Svensmark, Nir Shaviv, Jan Veizer, Sebastian Leuning, Fritz Vahrenholt and Nigel Calder.

3.5.1.1 Galactic cosmic ray flux is moderated by the heliosphere

Conversely, high-energy GCR come equally from all directions and are affected by the solar wind and the solar magnetic flux. The solar wind is super-sonic until it reaches ~94 A.U. where it goes subsonic in a region called the termination shock (Whang, Burlaga, & Ness, 1995); the distance of the termination shock from the Sun varies according to the strength of solar activity, and hence of the solar wind. The solar wind eventually slows and meets solar winds from nearby stars and comes to a stop, which is called the heliopause, this defining a volume of space called the heliosphere (Figure 3.13). The region between the termination shock and the heliopause acts as a barrier to lower-energy cosmic rays (those with energies of less than 1GeV) and it reduces their flux by ~90%.

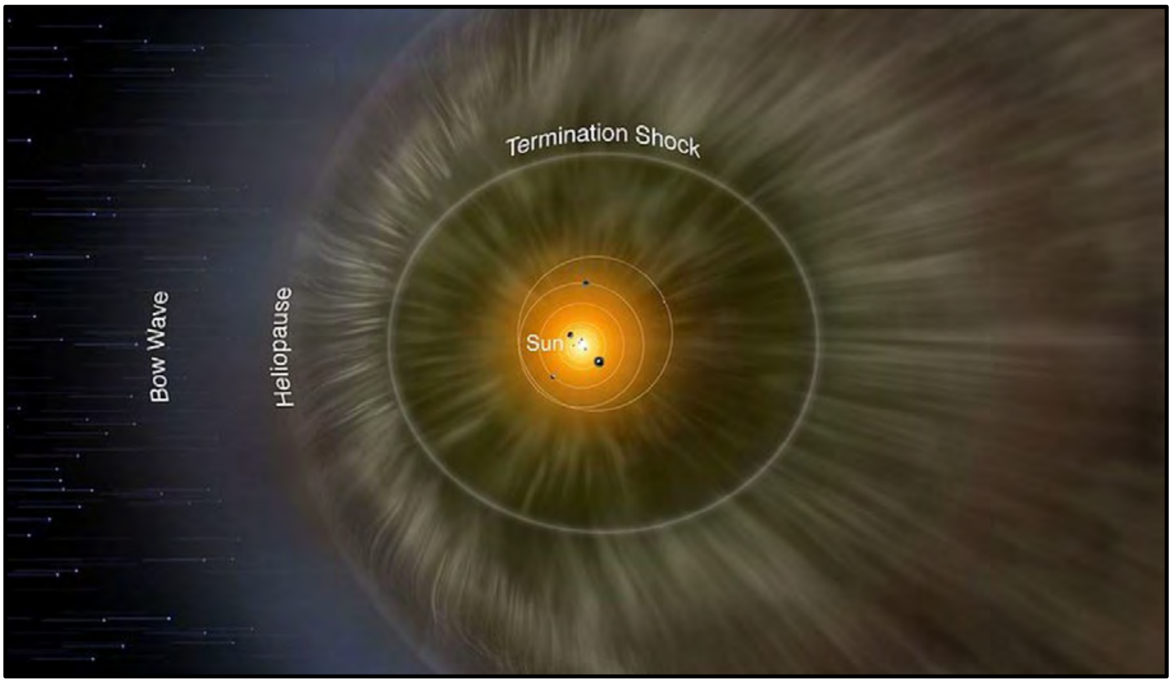


Figure 3.13 Heliopause – termination shock region of the heliosphere (Wiki, 2017).

The energy density of cosmic rays in interstellar space is 1 eV/c m^3; for comparison, starlight is 0.3 eV/c m^3, magnetic energy density is 0.25 eV/c m^3 and the cosmic microwave energy density is 0.25 eV/c m^3 (Washington.edu; 2017). The CRF constitutes ~15% of the natural background radiation on Earth, and generates unusual isotopes such as ^{14}C in the upper atmosphere. When measured on Earth's surface through proxies like ^{14}C, the CRF has varied by up to 200% over the last 40ky; the CRF is measured in many places currently.

The CRF which arrives in the upper atmosphere has a distribution peak in the 100 MeV – 1 GeV range; those with energies of >1GeV, can be described as being mainly relativistic protons, energies up to 300 EeV have been recorded, which is a far higher energy than any recorded natural gamma ray photon, and 10^7 times higher in energy than the protons the large hadron collider at CERN (the particle collider on the French-Swiss border) can produce (Shen, Heinz, Huovinen, & Song, 2011).

The galactic origin of the high-energy CRF is evident from observations of the absence of these rays coming from the direction of the Moon; i.e. the Moon absorbs them and so casts a cosmic ray 'shadow' in the sky (Amenomori et al., 2007). The flux of these cosmic rays when they arrive to Earth varies on million-year timescales due to the position of the Solar System in the Milky Way Galaxy (Nir J Shaviv, 2005), and on much shorter time-scales due to the level of solar activity (J. A. Lockwood, 1971). The Sun's magnetic field usually drives away approximately half of the GCR that arrive within the heliosphere; the region of space defined by the solar wind (Svensmark & Calder, 2007). The high-energy GCR which do arrive to Earth, impact atmospheric atomic nuclei in the upper atmosphere at 20km-30km and decay into swarms of pions and kaons, which then quickly decay into mass showers of relativistic muons. Muons are charged particles and have a lifetime of 2.2 microseconds (Allkofer & Jokisch, 1973) which means that they should travel no further than 660m before decaying, and that would not enable them to reach lower troposphere or the ground because these interactions first occur many kilometres up. But these muons are created in high-energy cosmic ray events and so are moving at relativistic speeds; time dilation allows them to survive long enough to reach the lower troposphere and some are even energetic enough to penetrate several kilometres into the ground. A high-energy cosmic ray event in the upper atmosphere results in a large shower of muons, cosmogenic nuclides and huge numbers of ionised particles on a pathway reaching all the way down through the atmosphere and into the ground. The cosmic ray-induced muon flux at the Earth's surface is approximately 10,000 per square metre per minute (De Pascale et al., 1993), muons decay into their smaller, but more stable brother the electron by emitting two neutrinos.

3.5.1.2 The solar activity amplifying mechanism

The solar activity amplifying mechanism is; solar activity affects the CRF through solar wind and magnetic field changes (Figure 3.17), this affects the ionisation rate in the atmosphere and so the nucleation rate and the rate of CCN production (Figure 3.20), the number of cloud droplets and the radius of cloud droplets changes – and so cloud sizes and properties change, affecting albedo and hence global temperatures (Svensmark, Enghoff, & Pedersen, 2013).

3.5.1.3 The CRF – climate link is through low clouds

The scientific discussion over the reality of the CRF – climate link through clouds has continued since the idea was first put forward by Svensmark in the 1990's. Good scientific work was done by Beer and his colleagues (Kissel, Mazaud, Channell, & Beer, 2000) on the Laschamp excursion of 40kya in an attempt to disprove the link. At that time, the Earth's magnetic field had reduced in strength by 90%. Proxy records for the CRF such as ^{14}C, $^{1\circ}$Be and ^{36}Ch showed that the surface CRF had increased by more than 50% - yet the trusted proxy for temperatures, ^{18}O showed that there had been no cooling. Puzzled, Svensmark pondered just why the solid prediction of his hypothesis under these circumstances for more cloud cover and hence, cooler temperatures had not materialised.

The answer lay in the nature of the cosmic rays themselves; it turned out that it's not just any cosmic rays that affect any clouds, but a specific high energy range of cosmic rays, that specifically affects low clouds. The breakthrough came when a German program (Heck & Pierog, 2000) became available for modelling high-energy physics related to energetic cosmic rays in the atmosphere called CORSIKA. The result was a refinement of the cosmoclimatology hypothesis, which in effect separated the cosmic rays which create changes in low clouds from the overall effect of the CRF, which collectively creates the atmospheric proxies for that flux; namely, the isotopes ^{14}C, $^{1\circ}$Be and ^{36}Ch. The program revealed that as much as 60% of the muons being produced in the atmosphere come from cosmic rays of such high energy that they are not affected by any changes in solar activity or in its magnetic field. This represents a flux base of muon generation, which only changes over millions of years due to the Solar System's path through the Milky Way's varying background flux of cosmic rays; or, due to large Milky Way events occurring, such as a starburst. Another 37% of muons are generated by cosmic rays of much lower energies; ones which could be affected by solar activity and magnetic field changes. The remaining 3% are of such low energies that even the relatively feeble magnetic field of the Earth can affect them. Simply put, the Laschamp Excursion did allow many more lower energy cosmic rays to enter the atmosphere, but the CRF of the higher energies – the only type which affect low cloud cover and hence temperatures – hardly changed.

3.5.1.4 Forbush decreases support cosmoclimatology

Forbush decreases are when the CRF arriving to Earth decreases suddenly, over the course of a few hours, perhaps by as much as 20% (Svensmark & Calder, 2007) the flux then slowly recovers, taking a few weeks to return to normal. These decreases (Figure 3.14) are known to be caused by shock waves in the heliosphere pushing away some of the primary GCR; the cause of the shock waves are sudden bursts of solar activity, for example coronal mass ejections (henceforth CME) (Cane, 2000). The final barrier to GCR reaching the Earth's atmosphere is the planet's own magnetic field, which forms the magnetosphere; the shape of the magnetosphere is determined by the strength of the Sun's magnetic field and the strength of its solar wind.

During a Forbush event, the solar wind suddenly increases in strength, the Earth's magnetosphere is buffeted, and changes in clouds appear (Svensmark, Bondo, & Svensmark, 2009). Ion production in the lower atmosphere is reduced, and as a consequence, the liquid water content of the clouds reduces by ~7%. It appears from these measurements that a large fraction of the Earth's clouds may be produced by atmospheric ionisation. Less cloudiness caused by lower levels of atmospheric ionisation from a Forbush event would mean that an amplifying mechanism for solar activity exists. Other short-term changes in GCR flux have also seen a causal link appear to cloud changes (Laken, Kniveton, & Frogley, 2010). The link identified by the authors is between short-term GCR flux changes and mid-latitude clouds between 30°- 60° both north and south.

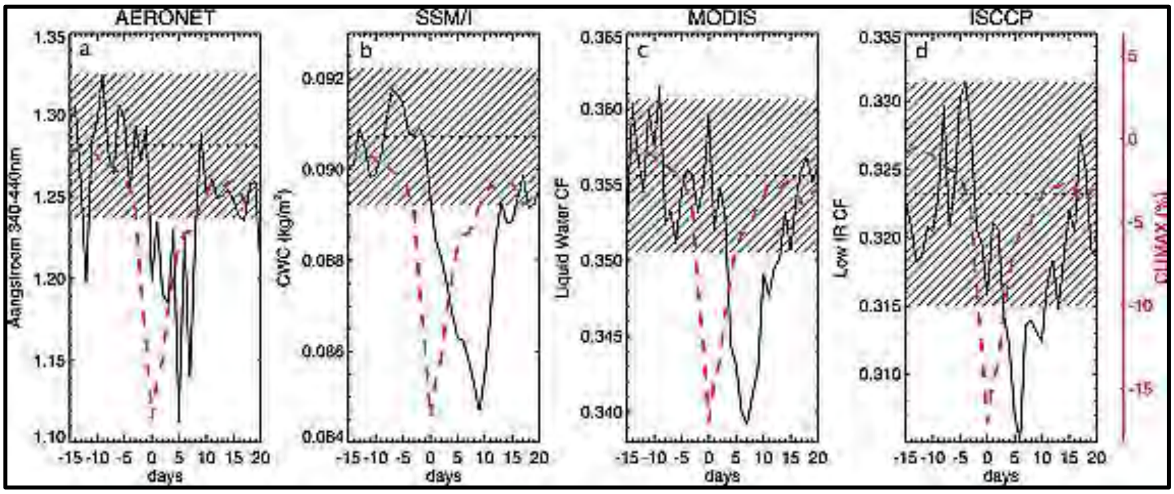


Figure 3.14 After Forbush events, water content falls 7% (Svensmark et al., 2009)

A hypothesis is put forward that the CRF – cloud link may be a second-order one; that is, cloud changes are only seen if atmospheric conditions are conducive. Bearing this in mind, the authors worked backwards from strong cloud changes to assess whether any solar changes had happened just prior. Of several possible solar climate drivers, only the rate of GCR flux underwent statistically-significant changes. This not only confirms a CRF-cloud mechanism, but it helps to eliminate other solar mechanisms. That this GCR link exists to clouds is still disputed in the literature (M. Lockwood & Fröhlich, 2007) (Kulmala et al., 2010) (Calogovic et al., 2010) (M. Lockwood, 2012); however, it must be noted that the link is specific to cosmic rays of a certain energy (1-10Gev), clouds of a certain latitude and height, and may also be specific to atmospheric conditions being 'right' for the link to occur (Svensmark & Friis-Christensen, 2007) (Yu & Luo, 2014) (Gaisser, Engel, & Resconi, 2016).

3.5.1.5 The correlation between low cloud changes and temperatures

A decline of 6% in lower tropospheric tropical cloud cover (15°N–15°S) has occurred 1984 – 2000 according to the international satellite cloud climatology project (Figure 3.15) and this change has been simultaneous with a rise in global temperatures of 0.4°C as measured by the global surface temperature dataset, HadCRUT3. Low tropical clouds are known to have a cooling effect; could this be an example of cause and effect, with the cloud reduction being the causative factor in the measured surface warming?

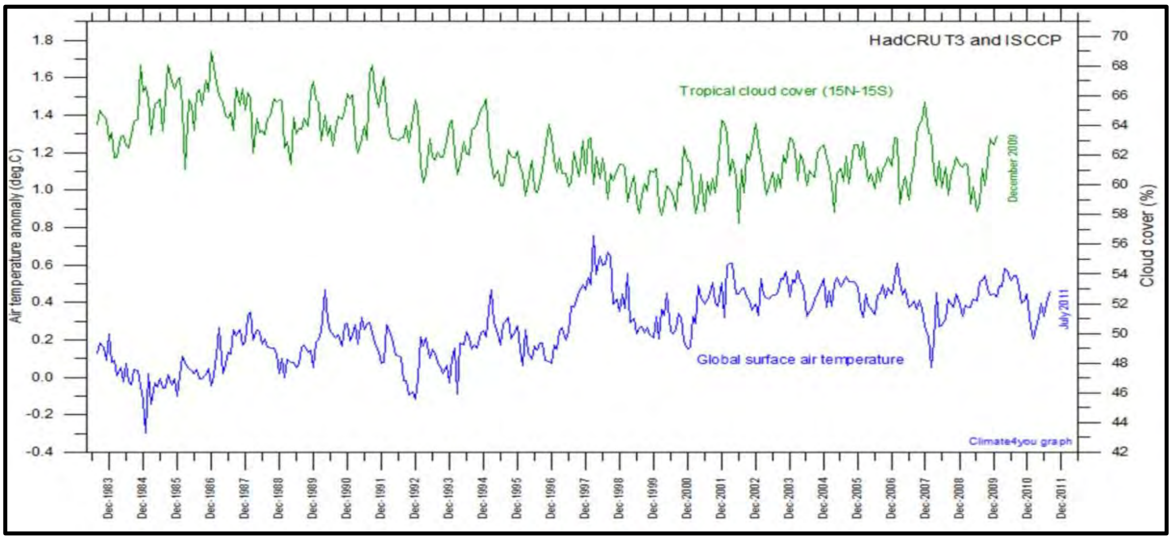


Figure 3.15 Changes in tropical cloud and global temperatures (Climate4you, ISCCP)

Scatter diagrams of low cloud cover vs global surface air temperatures indicate that a 1% fall in low clouds equates to a 0.06°C rise in surface temperatures (Figure 3.16).

Hence, a 6% fall in low cloud cover equates to a ~0.36°C rise in global surface temperatures, which is virtually all of the observed rise seen in HadCRUT3 data over this time period; it is within the margin of error. The mechanism to force this warming is that less insolation is reflected, and so a lower albedo is the cause. More solar short-wave energy (insolation) reaches the ground/oceans and is absorbed, causing more heating of the land, oceans and then by convection and radiation, the air above them. This fits with the warming seen on the land, in the oceans and in the lower troposphere, and also fits with the lack of warming seen in the upper troposphere. The dramatic cooling observed in the mesosphere and the stratosphere fits with the increased atmospheric CO_2 concentrations, which have been shown to cause this (Clough & Iacono, 1995) (Figure 3.36). However, the warming oceans is a factor that is hard to assign to increasing atmospheric CO_2, because the wavelength of the back-radiation from CO_2, cannot penetrate water (Irvine, 2014) (Figure 3.61). It seems logical to ascribe this warming trend to insolation increases.

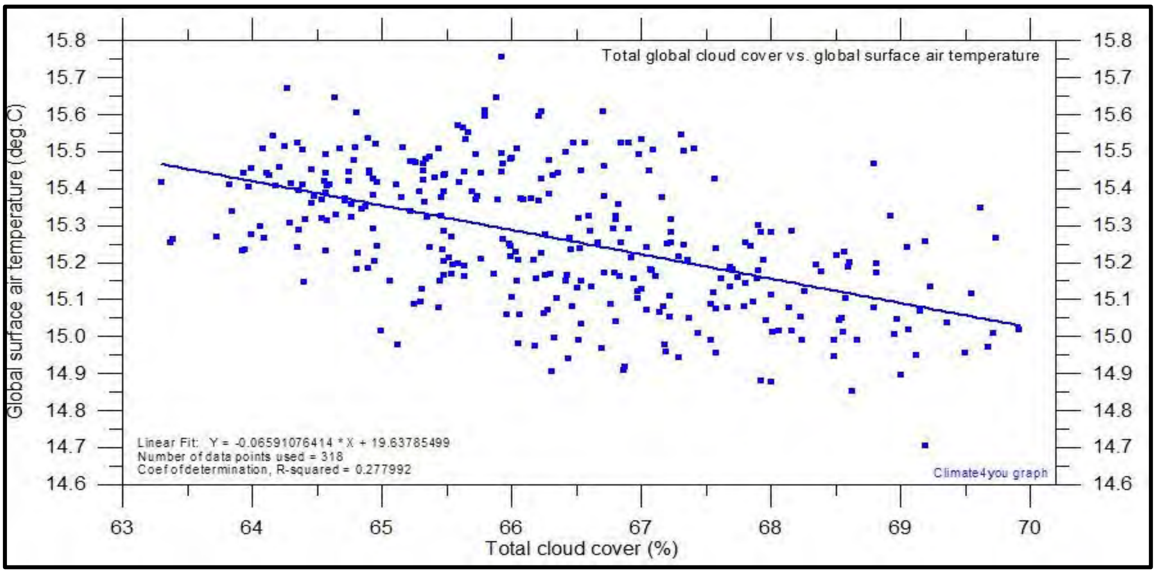


Figure 3.16 Scatter plot of cloud vs surface air temperatures (Climate4you, cloud)

According to early work in the field of cosmoclimatology by Svensmark (Svensmark & Friis-Christensen, 1997), GCR changes caused by the Schwabe solar cycle, change cloud cover by 3%, which in effect creates a surface forcing change of 0.5 W/m². It is known that high clouds have a warming effect, and low clouds generally have a cooling effect (except at night, and over the Antarctic and Greenland). Overall, clouds cool the Earth, and the effect is not small at ~20 W/m² (Svensmark, 2007b). During the 20th century, GCR flux fell (Yu & Luo, 2014) (Figure 3.19), so there will be less low cloud cover, which, because of the net cooling effect of low clouds, leads to a warming planet.

3.5.1.6 The correlation between the CRF and numbers of Sunspots

There exists a strong correlation between the flux of cosmic rays at the Earth's surface, and the Sunspot count (Figure 3.17). This is thought to be one link in the mechanism which amplifies known, relatively small solar changes sufficiently to explain the range of natural climate variability that is seen not only in proxy records, but also in the contemporary measured surface temperature record.

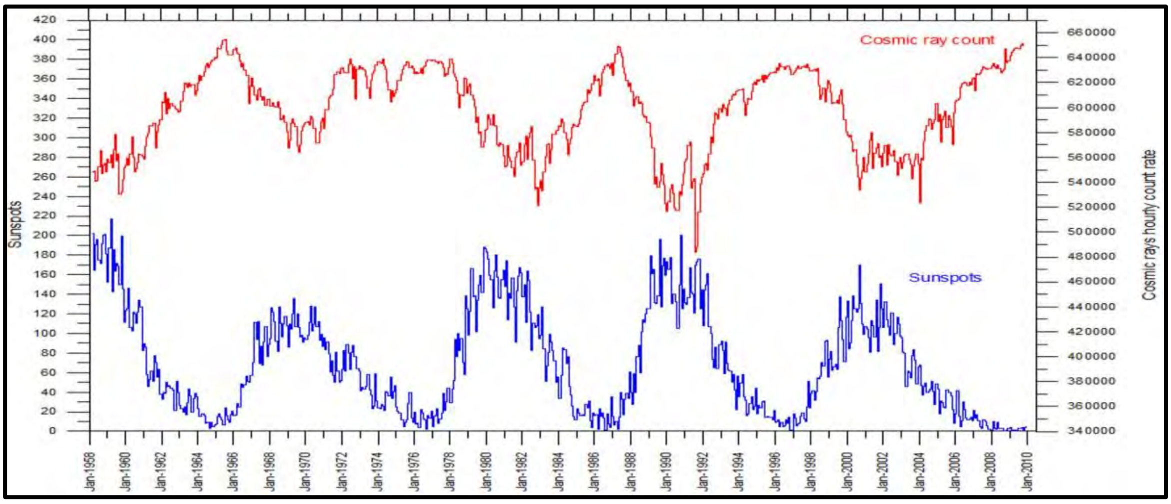


Figure 3.17 Sunspots correlate well with CRF (Climate4you, CRF and Sunspots)

3.5.1.7 The global surface temperature – cosmic ray correlation

Changes in global surface temperatures (Figure 3.18) blue curve, are plotted against the change in the surface CRF, red curve. When the effects of El Ninos and volcanos are removed, the correlation is corr. = - 0.47. These correlations between climate change and changes on the Sun, are seen not only over decades, but on century time-scales (Y.-M. Wang, Lean, & Sheeley Jr, 2005) (Figure 3.19).

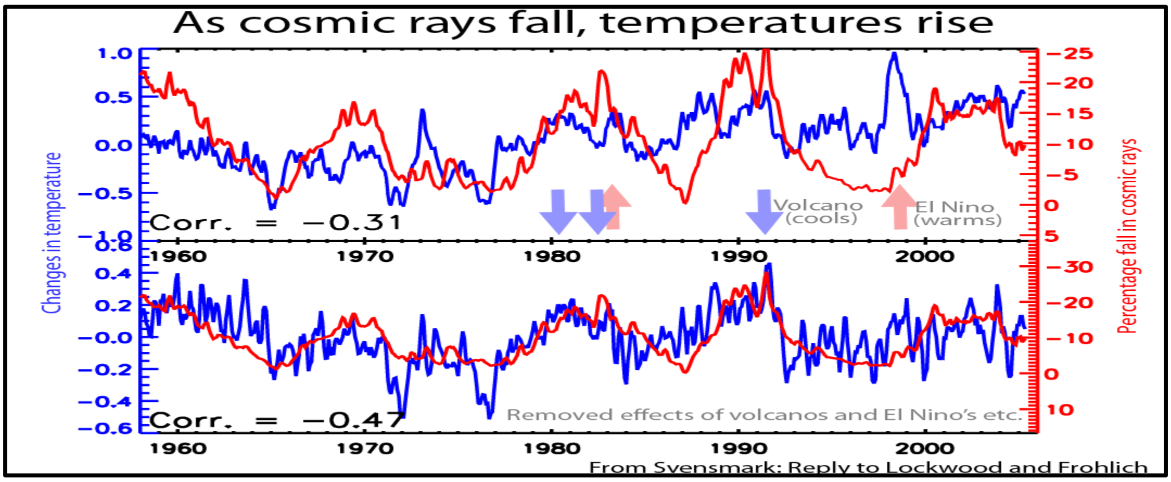


Figure 3.18 CRF and temperature correlate well (Svensmark et al., 2009).

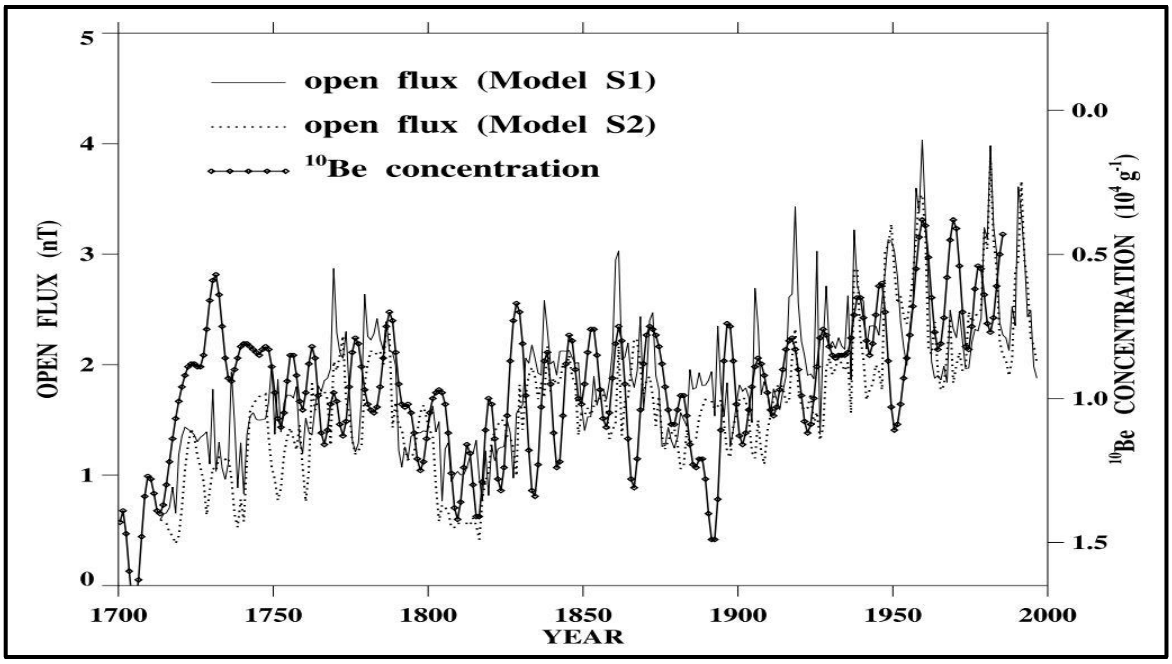


Figure 3.19 Solar flux since 1700 against a CRF proxy, ^{10}Be (Yu & Luo, 2014).

3.5.1.8 Cosmoclimatology; the solar activity amplifying mechanism

The relationship between climate and TSI has been investigated in many studies, but the first investigation of a relationship between production of CCN and the temperature change that is induced by the regular Schwabe solar cycle (Yu & Luo, 2014) was undertaken only recently. Natural climate drivers such as the Sun were the only possible cause of most or all climate changes prior to 1950; even the IPCC acknowledges this. Yet the simple facts are that if Schwabe cycle and longer, century-scale TSI changes are as small (Y.-M. Wang et al., 2005) as is now claimed in the IPCC reports (Allen et al., 2014), then recent historical decadal and centennial climate changes must have also been very small – but it is known that they weren't; (H-J Lüdecke, Hempelmann, & Weiss, 2013) (Humlum, Solheim, & Stordahl, 2011; Marcott, Shakun, Clark, & Mix, 2013). For example, TSI variations must have been at least 3 times larger (Foukal et al., 2006) than is stated in the IPCC reports, otherwise, as an example, the severe LIA cooling centred on 1690 would not have been possible.

This leads to two probabilities; that the TSI changes were not really that small, and/or a strong amplifying mechanism exists (Pulkkinen, Nevanlinna, Pulkkinen, & Lockwood, 2001). A stronger solar influence is required to explain the historical records and the many proxy records which all testify to the reality of large climate variability. When considered on balance, the likelihood is that both are true. Even on decadal time-scales, the common Schwabe cycle needs an amplifying factor of 3 (Douglass & Clader, 2002) to explain the signature that is seen in the climate record. The historical TSI changes have been examined in other work, and were found to have been much greater than the changes reported in the IPCC reports (Scafetta & Willson, 2014). As for a solar amplifying mechanism, several strong possibilities exist – primary among these is through the solar activity – GCR – cloud link (Figure 3.20) (Yu & Luo, 2014).

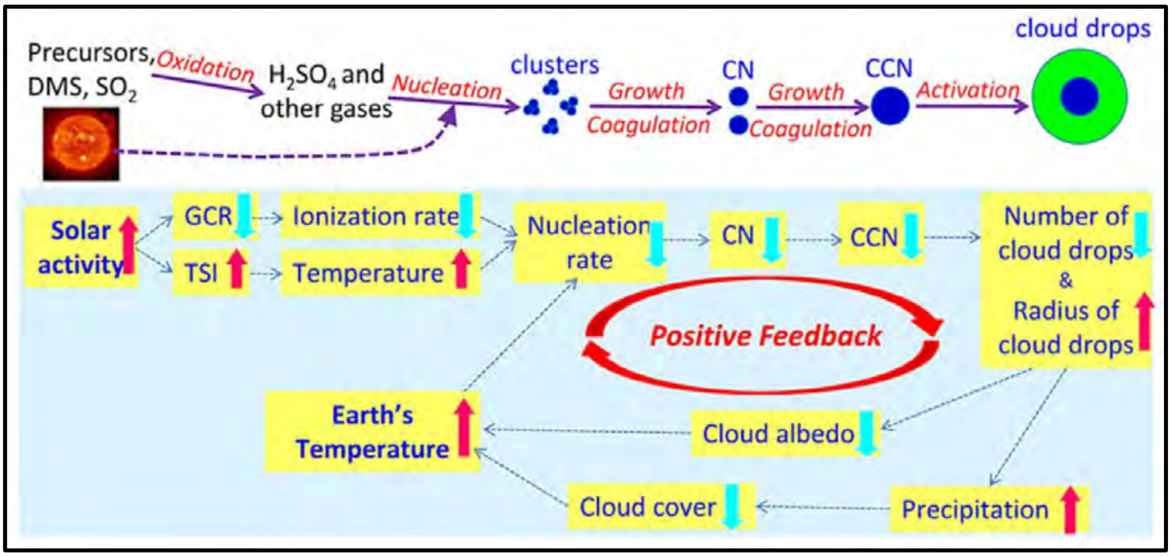


Figure 3.20 How solar activity is amplified in cosmoclimatology (Yu & Luo, 2014).

The mechanisms mean that Schwabe – related surface temperature changes are significant at ~0.2°C (Camp & Tung, 2007), and they increase with height to ~0.8°C in the stratosphere (White, 2006). Yu and Luo found that changes in ionisation rate and temperature associated with the Schwabe solar cycle cause significant changes in CCN production rates, which then exhibit large spatial, seasonal and hemispheric variations (Yu & Luo, 2014).

3.5.1.9 GCR of 1+ GeV reach the lower troposphere and influence clouds

Astrophysicist Nir Shaviv has investigated the solar activity – climate link in a brilliant and unique way; by using the oceans as a calorimeter (Nir J Shaviv, 2008). The findings indicate that total radiative forcing changes were 5-7 times greater than just TSI variations alone. The largest of these amplifying mechanisms were through the CRF – cloud link. Specifically involving the GCR flux of high-energy protons of >1GeV, which are those with enough energy to reach low tropospheric clouds and influence them through muon bombardment (Figure 3.21).

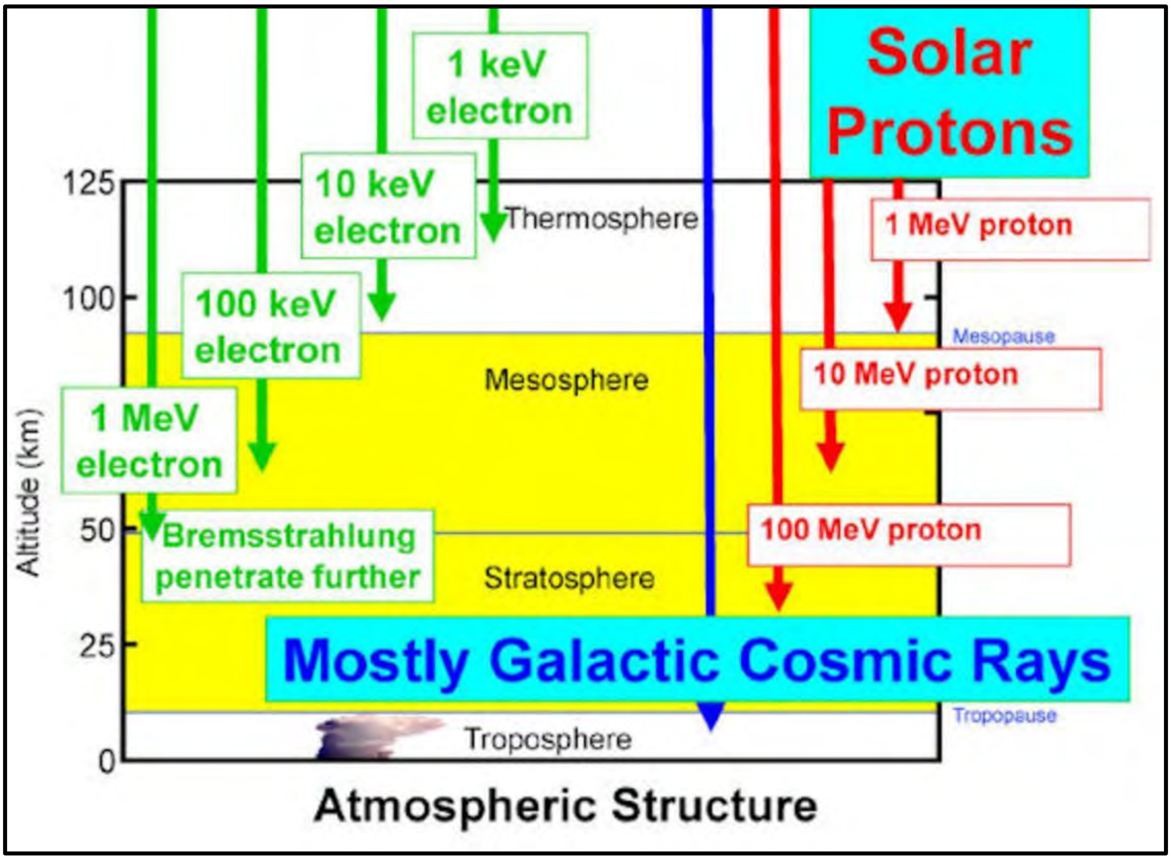


Figure 3.21 CRF of >1GeV reach the lower troposphere (Nir J Shaviv, 2008)

3.5.1.10 The correlation between solar activity and climate in the last 1ky

All recorded major climate changes of the last 1ky are represented in this graph of the change in ^{14}C isotope – a solar activity proxy, from tree rings (Figure 3.22). Clusters of solar grand minima such as are observed here with the Oort, Wolf, Sporer, Maunder and Dalton minimums also appear to be associated in periodicity with the 2,300 year Hallstatt solar cycle (Nussbaumer et al., 2011). The modern maximum also appears clearly in this ^{14}C record. A very strong correlation is also seen between the solar proxy ^{14}C and the temperature proxy ^{18}O during the period 6-9kya in Oman (Figure 3.23). Support for the reality of these recent solar-induced climate changes is global; a 470-year record from East Antarctica includes all these changes represented in differing isotopes (Thamban, Laluraj, Naik, & Chaturvedi, 2011). Also revealed is a significant 2.7°C warming in the isotope ^{18}O over the period from the Sporer minimum to the present peak of the modern maximum.

3.5.1.11 Correlation between the CRF and climate on many time-scales

Extremely strong coherence between solar activity proxies and climate (monsoon) proxies 6-9kya have also been found (Neff et al., 2001) (Figure 3.23).

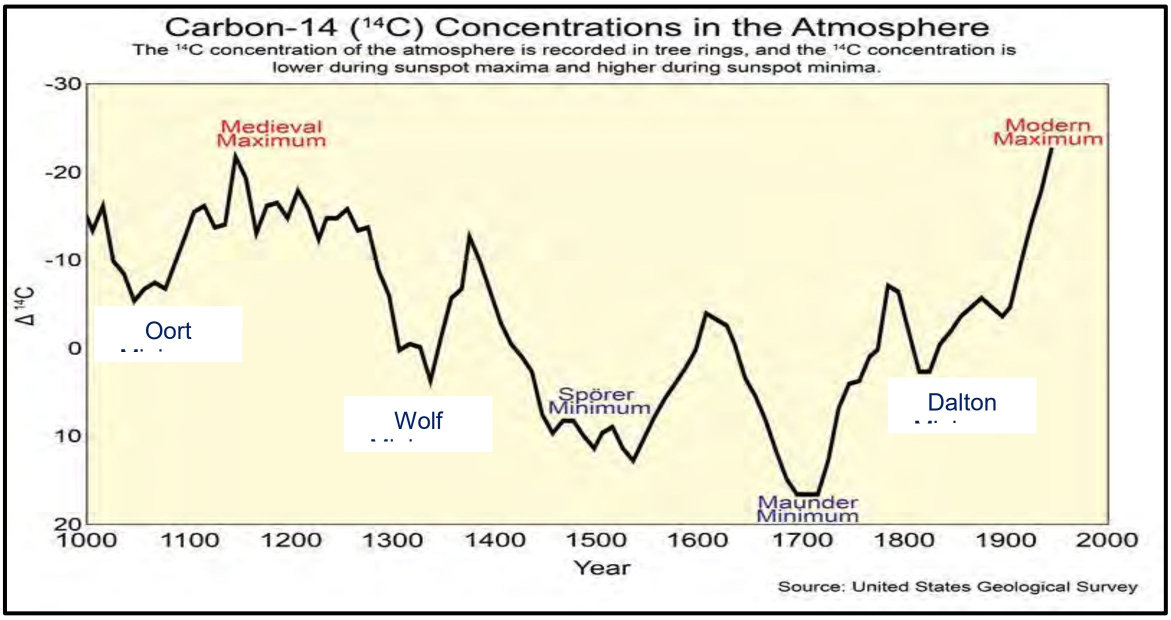


Figure 3.22 Solar proxy ^{14}C matches all climates since 1000AD (Nussbaumer et al., 2011)

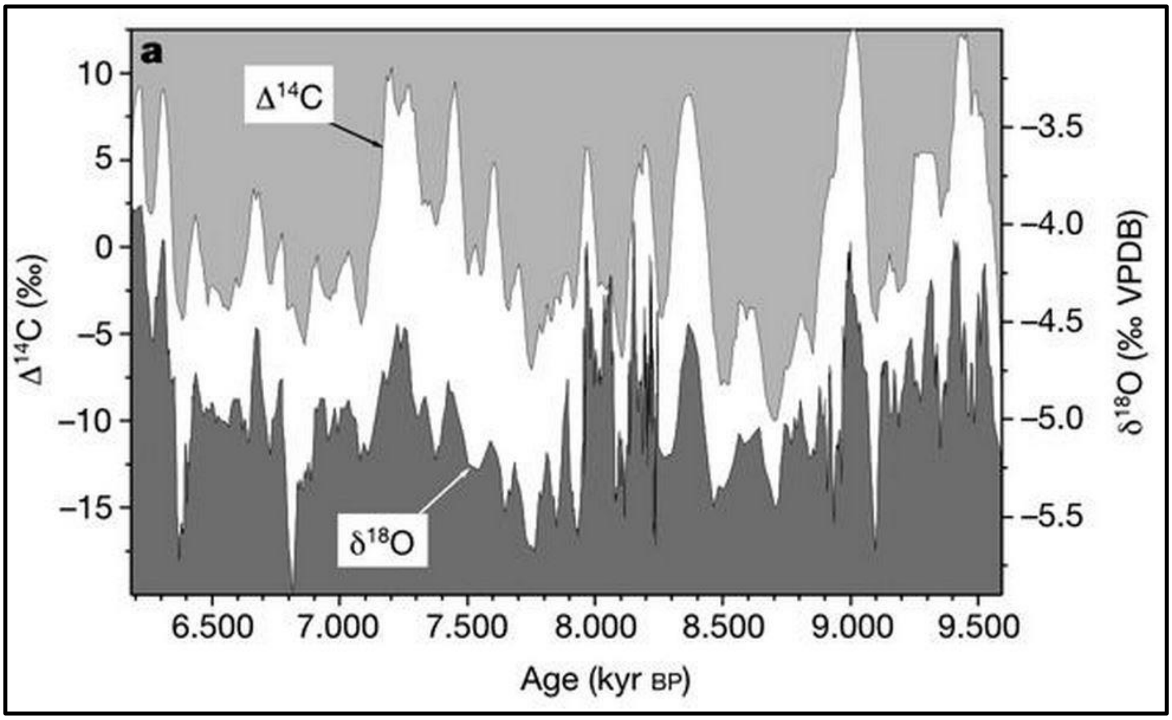


Figure 3.23 Solar activity proxy and a monsoon proxy 6-9kya in Oman (Neff et al., 2001).

CRF is correlated with changes in the climate on Earth on all time-scales, including over hundreds of millions of years, tens of millions, millennial, centennial, decadal, annual and daily. Historical CRF can be gauged from proxies such as Beryllium 10, (^{10}Be) which is formed in the atmosphere by the cosmic ray spallation of oxygen atoms. The isotope is then deposited by precipitation onto the surface and can be compared to a temperature proxy such as Oxygen 18 (^{18}O). CRF is known to be anti-correlated with solar activity.

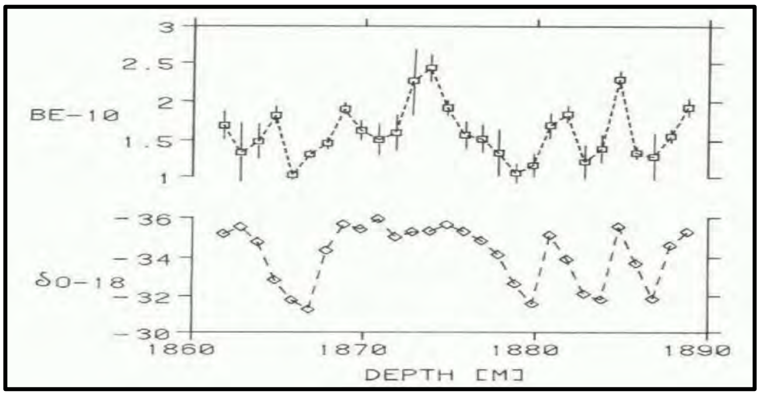


Figure 3.24 ^{10}Be and ^{18}O from the DYE3 ice core in Greenland (Beer et al., 1984).

For example, when ^{10}Be and ^{18}O from the DYE 3 (Beer et al., 1984) (Figure 3.24) ice core in Greenland from a depth corresponding to 30 - 40kya are compared. They correlate well; this signals the existence of a causative relationship, with millennial-scale CRF changes triggering events which cause a millennial-scale change in the surface temperatures on the Greenland ice sheet.

3.5.1.12 The very strong influence of clouds in the climate system

Clouds are poorly represented in climate models, yet clouds are known to have a very strong effect on the climate system, this effect operating mainly through albedo changes. A small change in albedo has a strong effect on the temperature of the Earth, and if the change persists, this will also cause climate change. The Earth's albedo changes can best be measured by earthshine; simply by measuring how much light the Moon receives from Earth on its unlit side. In this way, a strong negative feedback though cloud changes was measured in response to the warming of the 1998 El Nino (Pallé et al., 2009) clouds were found to increase the Earth's reflectance beginning in late 1998 until mid-2000, so countering the warming effects of the El Nino. There were also found to be large decadal changes occurring in the albedo or reflectance of the Earth, which could be a negative feedback mechanism controlling the planet's temperature. A strong negative feedback mechanism is seen in the outgoing longwave radiation (OLR) (Figure 3.60).

Another recent and perhaps surprising discovery is that the Northern Hemisphere and the Southern Hemisphere's albedos are equal to within 0.2 W/m² (Stephens et al., 2015). There are large differences between the Northern and the Southern Hemispheres;

the reflective north being mostly land and the darker and so more absorbent south being mostly oceans, and overall of course, the surfaces have vastly different albedos – so their surface temperatures should on average be very different. Yet when clouds are included, their albedos are virtually the same, which mostly evens out their temperatures. This can only be a result of a strong negative feedback mechanism; the close symmetry in hemispheric albedos, is caused by the buffering of the clouds themselves.

Another buffering effect has also been found; it is known that there is a seasonal cycle of solar flux caused by the eccentricity of the Earth's orbit. The Earth's orbit is egg-shaped, this means that every year the distance to the Sun varies from 147.5 M km at perihelion to 152.6 M km at aphelion (Table 3.2). Perihelion (closest approach) occurs each year on January the 3rd and at that time the top-of-atmosphere (henceforth TOA) insolation is 1,413 W/m². aphelion (greatest distance) occurs each year on July 3rd and at that time the TOA insolation is 1,321 W/m².

Table 3.2 Seasonal surface insolation changes (Taube, M. 2012).

Position	Insolation W/m²	Earth sphere W/m²	Albedo 29% W/m²
Perihelion Jan 3	1,413	353.25	250.8
Aphelion July 3	1,321	330.25	234.48

When allowances are made for the shape of the Earth, and a 29% albedo, the average surface insolation is expected to be 250.80 W/m² at closest approach and 234.48 W/m² at greatest distance; that is, a difference every 6 months of 16.32 W/m². This is one thousand six hundred times the average change in forcing, estimated to have been caused by human GHG (which is of order ~0.01 W/m²) over the same time period (Feldman et al., 2015), and eccentricity is just one contributor out of many, to natural climate variability. This puts the alleged anthropogenic CO_2 forcing into better context, and perhaps goes some way towards explaining just why this forcing has been so difficult to measure.

It will be noted that a change in albedo of just 1% leads to a net surface change in forcing of at least 3.31 W/m², which is still greater than the total net anthropogenic forcing listed in AR5 (Team et al., 2014) of 2.29 W/m² in the 261 years since 1750. Albedo has been found to have a seasonal variability of over 3%, with a higher albedo occurring in the southern summer, and a lower albedo occurring in the northern summer (Stephens et al., 2015), little research has been done yet into these large negative feedback mechanisms.

Seasonal variations in insolation due to eccentricity can also be used to estimate the climate sensitivity. Original work by Cederlof (Cederlöf, 2014) uses empirical data to create a simple climate model to estimate the impact of doubling atmospheric CO_2, using the IPCC's forcing figure of 3.7 W/m². The key is to separate the Northern Hemisphere from the Southern Hemisphere and treat them separately, because their responses to the seasonal forcing changes are very different. A hysteresis due to inertia of perhaps one month was found to exist after the regular 16.32 W/m² seasonal surface insolation forcing change (caused by the Earth's eccentricity); but the temperature change was muted in the Southern Hemisphere – the Northern Hemisphere experiences a much greater temperature swing in response. The resultant global climate sensitivity to CO_2 as per these model results, is in the very low range of 0.23°C to 0.32°C; this would probably be too low to measure.

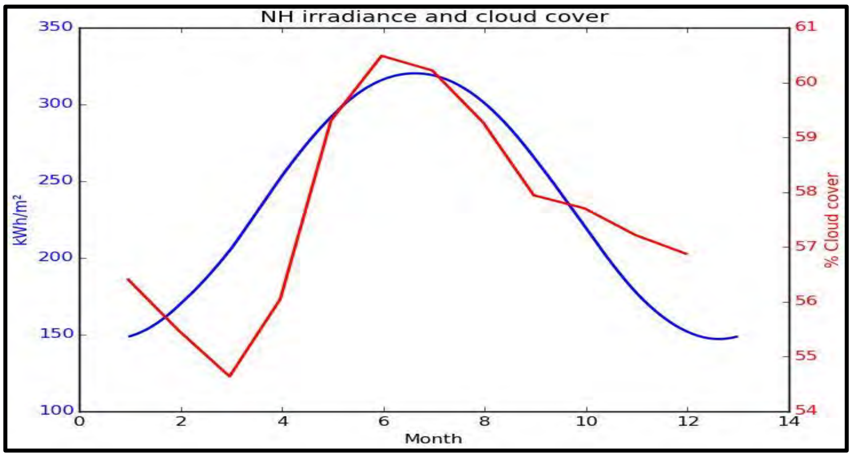


Figure 3.25 Northern Hemisphere irradiance changes vs cloud cover (Cederlöf, 2014)

Further work by Cederlof (Principia Scientific, 2017) into the eccentricity-induced seasonal insolation change and cloud cover changes led to an examination of NASA's CERES data to explore any possible links between the two (CERES, 2017). The result is Figures 3.25 and 3.26 which show a previously unknown and strong correlation between the seasonal irradiance variation and cloud cover changes in each hemisphere when assessed separately; no significant correlation is seen when assessed globally. The importance of this discovery cannot be understated since it means that *there exists a strong negative feedback mechanism* in the climate system, which *operates through clouds* to reduce the effects of large seasonal insolation changes on the Earth's surface. This has problematic connotations for the positive water vapour and cloud feedback, which is an integral part of the EGGWH.

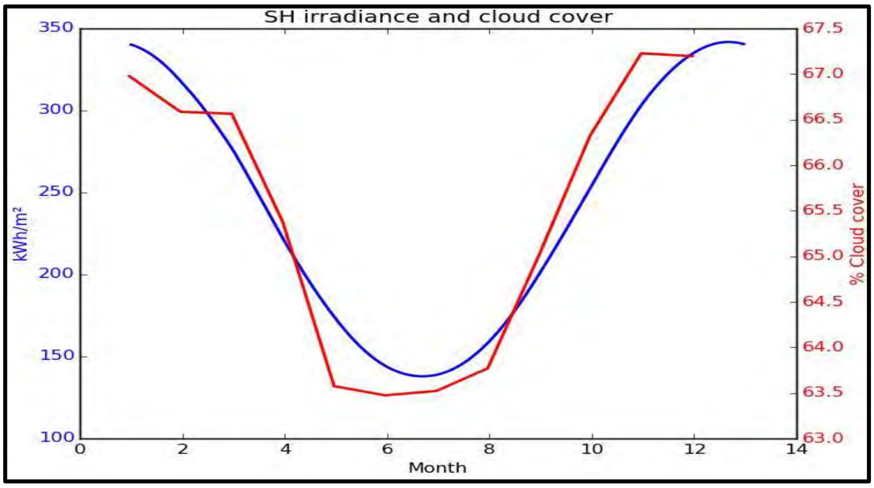


Figure 3.26 Southern Hemisphere irradiance changes vs cloud cover (Cederlöf, 2014)

Also, to be noted is that the Northern Hemisphere is warmer than the Southern Hemisphere, despite the fact that the Southern Hemisphere's surface insolation is on average, higher. The reason for this discrepancy is because there is a far higher average cloud cover in the Southern Hemisphere. According to CERES data, the Southern Hemisphere averages 65.5% cloud cover, and the Northern Hemisphere averages 57.6%. From the differences in cloud cover and insolation, Cederlof calculates from this, a climate sensitivity to CO_2 of 0.4°C which compares well with the 0.3°C from the previous work on seasonal variations.

Climate models used by the IPCC researchers do not have the same regulation of albedo or degree of hemispheric symmetry that is created by the action of clouds. The obvious and strong negative feedback that is displayed here by clouds on a global and hemispheric scale, is completely at odds with the proposition that clouds do the exact reverse where CO_2 is involved; namely, that they positively reinforce the initial warming from CO_2 rather than act to mitigate it. It is difficult to maintain the proposition of positive feedback from clouds to a CO_2 forcing, if a measured solar forcing produces a measured negative feedback from clouds. Why should they be different? Invoking a large positive feedback through water vapour to any CO_2 forcing, also flies in the face of logic, since this would mean that the climate system has to be intrinsically unstable, and this instability is not seen anywhere in the climate record.

3.5.1.13 The 34 million-year CRF cycle and its climate change link

A cycle of ~34My has been discerned in the proxy CRF, this appears to be related to the Sun's up and down motion through the plane of the Milky Way as it continues on its

250My orbit of the galaxy. This dolphin-like behaviour would logically result in Earth being subjected to a regular variation in the CRF due to its proximity or otherwise to the centre of the flat disk of the Milky Way, which is known to be a strong source of cosmic rays (Aharonian et al., 2005). This variation has been found in the ^{18}O proxy data; and also, does correlate with known climate changes (Svensmark, 2007b) (Figure 3.27).

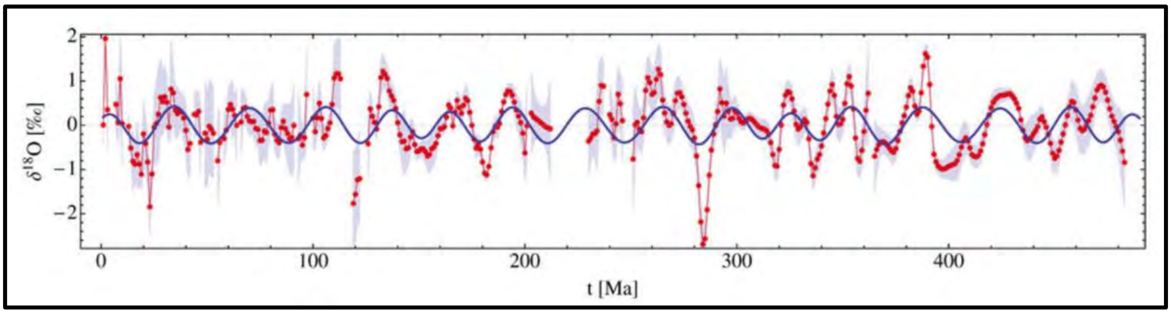


Figure 3.27 Detrended ^{18}O vs a 34My waveform (Nir J. Shaviv, Prokoph, & Veizer, 2014)

3.5.1.14 The 135 million-year CRF cycle and its climate change link

On medium time-scales – tens to hundreds of millions of years - the variability of the Sun plays a smaller part in climate change, and the Solar System's position in the Milky Way Galaxy plays a larger part. On these medium time-scales the much slower changes in the CRF itself have the greater influence and result in medium term, large changes in climate. The Milky Way's four main spiral arms are known to be density waves which sweep through the disk of the galaxy; (Yuan, 1969) they are not solid features which orbit like stars do. The density waves compress cold molecular gas clouds and trigger star formation (Elmegreen & Elmegreen, 1986).

The CRF is known to increase when the Solar System passes through one of the Milky Way's spiral arms, and to decrease between them (Nir J Shaviv, 2002). This is because greater high-mass star formation rates (and hence supernovae formation rates) are associated with the leading edges of all spiral arm density waves. Many cosmic rays of the right energy to penetrate to the lower atmosphere, originate in supernovae remnants. A 135My cycle in CRF has been shown to exist, and this cycle also appears to be correlated with known climate changes (Nir J Shaviv, 2002; Nir J. Shaviv et al., 2014). The descent into the present ice age, starting 90Mya, correlates very well with the Solar System's entry into the Sagittarius-Carina spiral arm, and the more recent cooling (last 15My) with starbursts and our entry into the Orion spiral arm segment (Nir J Shaviv, 2003) (Figure 3.27). Shaviv works with meteorites and Veizer with brachiopods as both try to discover the extent and rapidity of phanerozoic climate change, and its relationship to Solar and astronomical changes (Figure 3.28).

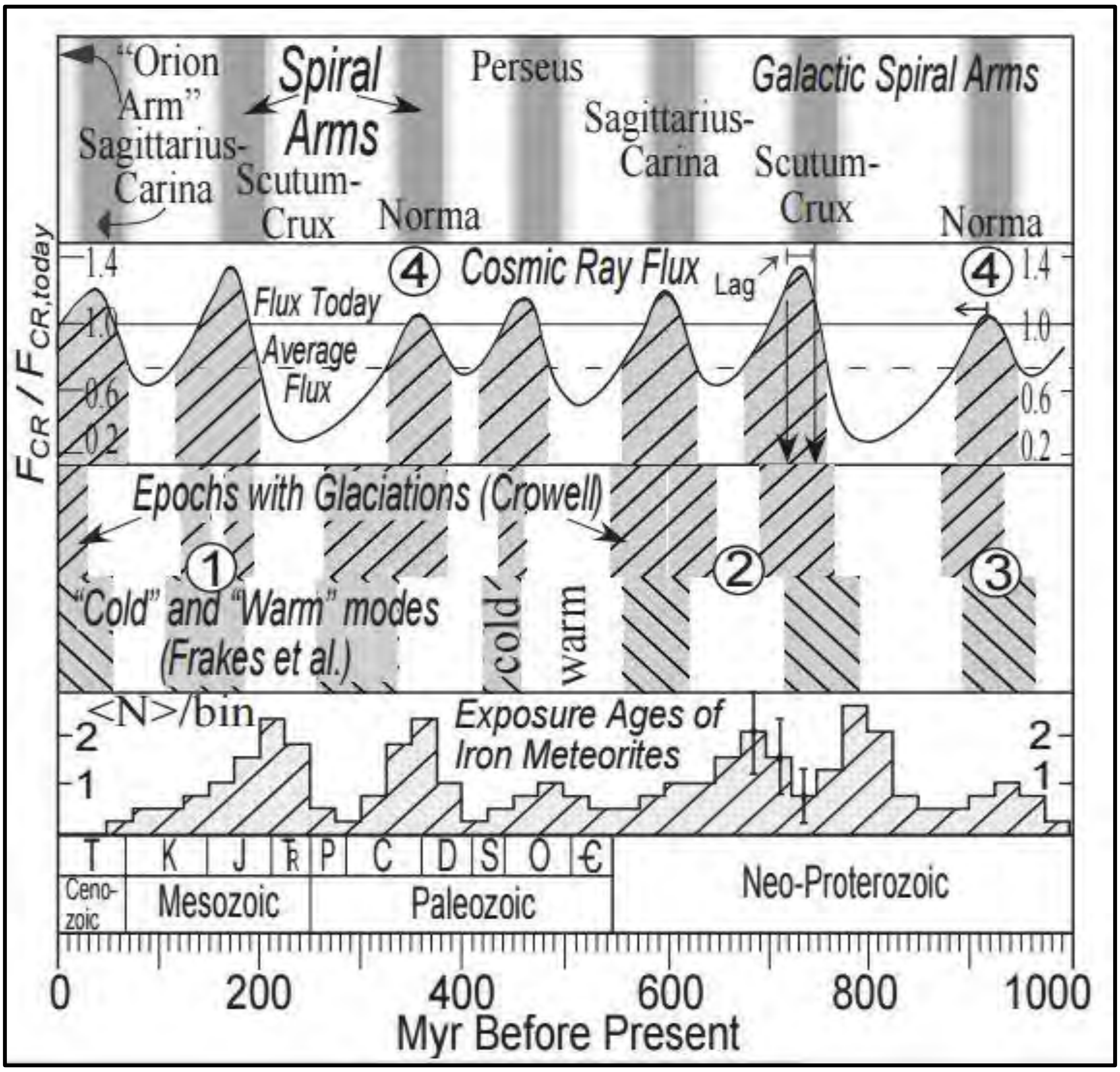


Figure 3.28 Correlation between ice ages and spiral arm passages (Nir J Shaviv, 2002)

3.5.1.15 Starburst events correlate with known climate changes on Earth

Another source of increasing cosmic rays is when there is a starburst event in the Milky Way; these can happen during a merger event with a dwarf galaxy or because of an interaction of galactic nebulae with incoming high velocity clouds (Tenorio-Tagle, Franco, Bodenheimer, & Rozyczka, 1987). Rapid star formation occurs because of the collisional nature of interstellar molecular clouds, merger events like these can trigger a very large starburst of high-mass stars. Approximately 15Mya, a very large starburst event of 10^{56} ergs occurred, involving ~100,000 type II supernovae in the central regions of the Milky Way (Hartmann, 1995). This event seems to be correlated with a sudden and severe fall in temperatures on planet Earth, which caused the re-glaciation of the frozen continent of Antarctica after it had melted during the mid-Miocene climate optimum (Zachos, Pagani, Sloan, Thomas, & Billups, 2001) (Figure 3.29). A series of further starburst events of ~10^{54} ergs happened 1-3Mya in the central regions of the Milky Way, again involving thousands of type 2 supernovae (Hartmann, 1995), at the same time, the Earth's climate continued to cool even further, (Ravelo, Andreasen, Lyle, Lyle, & Wara, 2004) sending Earth deep into the current ice age; (Figures 3.29 and 3.34) is this all a coincidence? Or are CRF change → cloud changes a persistent causation factor of the Earth's natural climate variability on these medium time-scales as it is on short time-scales?

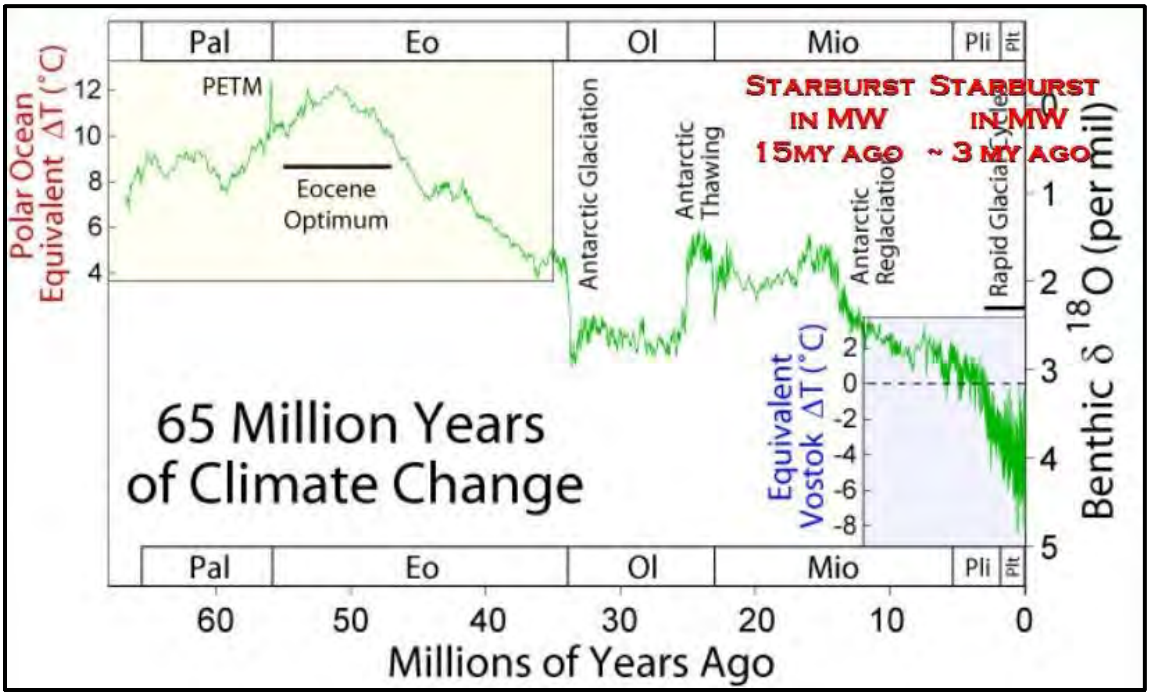


Figure 3.29 65My of climate change shows sudden changes (Wiki commons, 2017)

As was noted earlier, albedo changes are a very powerful agent of climate change, and an increased CRF alters low cloud cover in such a way that albedo in increased – and as already mentioned, every 1% change in albedo imparts a large forcing on the climate system of ~3.4 W/m², which is equivalent to a global temperature change of ~0.9 K.

The proxy record of climate changes over the last 250My (one orbit of the Milky Way Galaxy) show that for most of this period the Earth was much warmer than it is now, and has experienced a slowly declining temperature for the last 90My. This scenario correlates well with nearby star cluster formation rates, with a low at ~190Mya, then moderate formation rates, a low again at ~100Mya and then rising rates of star formation to the present, with sudden bursts at 90Mya, 30Mya, 15Mya, 10Mya and 3Mya (de la

Fuente Marcos & de La Fuente Marcos, 2004) (Figure 3.29). Further back in time, there was a nearby massive starburst ~0.45Gya (Hernandez, Valls-Gabaud, & Gilmore, 2000) (de la Fuente Marcos & de La Fuente Marcos, 2004) which correlates with a sudden and very deep ice age occurring at that time (Figure 3.29). Further back, it is possible that the 'Snowball Earth' events of the Proterozoic, 2.3Gya where the entire planet froze over pole to pole could have been triggered by huge Milky Way starbursts triggered by mergers or interactions with dwarf galaxies (Kataoka, Ebisuzaki, Miyahara, & Maruyama, 2013).

The Milky Way is known to have been constructed over a period of ~12Gy, and the central bulge and halo stars are the oldest, at about this age. The disk has a thick section of stars which formed ~8Gya and a thin, larger disk of which the Solar System is a part, which comprises of stars born 0 – 6Gya (Yoachim, Dalcanton, 2006). It is also known that the Milky Way Galaxy has been built in stages and by gravitationally pulling in gaseous material and dwarf galaxies along relatively dense, filamentary lines (Wakker et al., 1999). From the existing spiral shape of the Milky Way, it is also known that there has not been a catastrophic collision (yet) with another large galaxy, otherwise the spiral shape would have been lost. It appears though, that regular, and strong – but not catastrophic - starbursts are a feature of the evolution of the Milky Way Galaxy, as they are of other similar spirals.

The Milky Way is not classified as a starburst galaxy, and the star formation rate is on average a thousand times less in the disk than in the central regions, (where an unusually large cluster of type 'O' high-mass stars was discovered) (Serabyn, Shupe, & Figer, 1998). Still, starbursts do appear, and they also seem to be fairly cyclic on long time-scales, with one occurring every 0.4Gy ±0.1Gy (de la Fuente Marcos & de La Fuente Marcos, 2004). This regularity would be easier to explain by the action of spiral arm density waves than by interactions caused by incoming material. The more recent and known starbursts at 450Mya, 350Mya, and one at 50Mya (Majewski et al., 1999) (the latter probably related to the recent passage of the Sagittarius dwarf spheroidal Galaxy) are all well correlated with deep ice ages in the proxy climate record (Figure 3.30).

The alternative explanation for ice ages, according to the EGGWH, is that CO_2 levels were depressed by chemical weathering events, such as during the deep Ordovician - Silurian ice age (Porada et al., 2016). A more comprehensive treatment, covering the entire Phanerozoic period of climate change is given by Salzman (Saltzman, 2002). He felt the need to introduce a new factor; internal instability in the climate system, to explain measured proxy changes that did not seem to be covered adequately by CO_2 forcing movements.

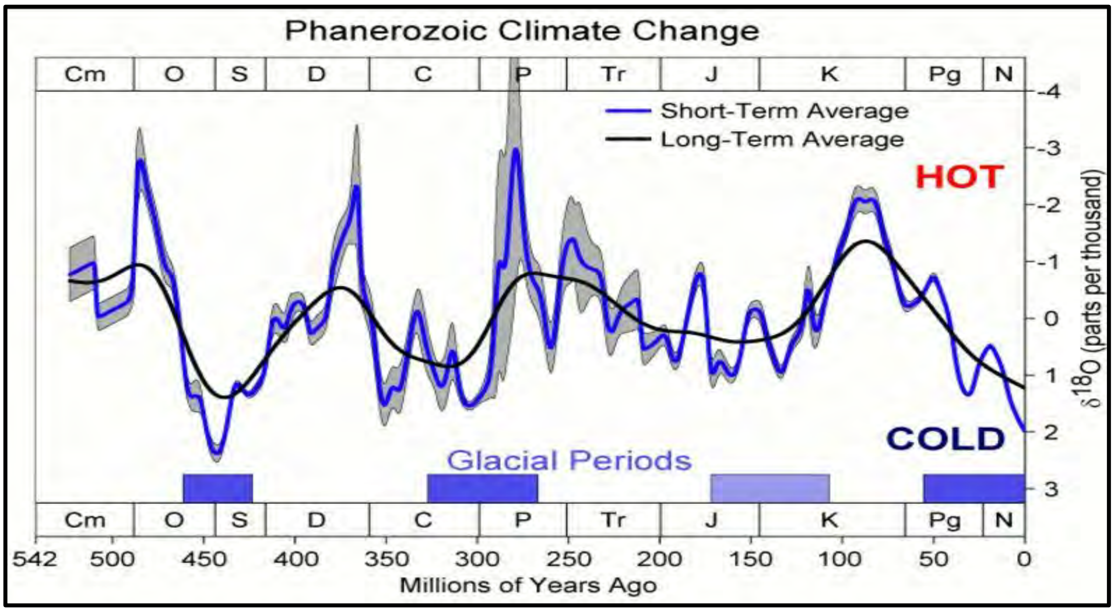


Figure 3.30 Phanerozoic; cooling over the last 90My (Nir J Shaviv & Veizer, 2003)

3.5.1.16 Experimental support for the formation of aerosols by cosmic rays

When Svensmark first put forward his ideas to the climate community in London, he was met with derision and scepticism; not the interest that he had anticipated. Experimental proof was demanded, but he had no apparatus and it took several years to raise the funds to build it. But when the apparatus was completed, Svensmark's hypothesis (Svensmark, 2007b) was given a boost after he conducted an experiment which aimed to find out if the action of cosmic rays could result in the formation of CCN in the atmosphere, and the results were encouraging (Figure 3.31).

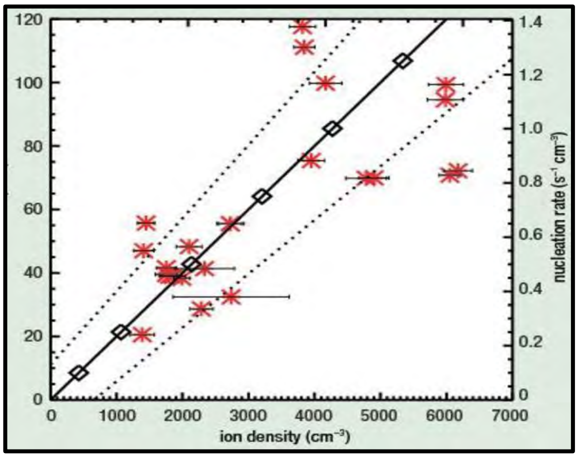


Figure 3.31 Svensmark's cloud chamber shows nucleation rates (Svensmark, 2007b)

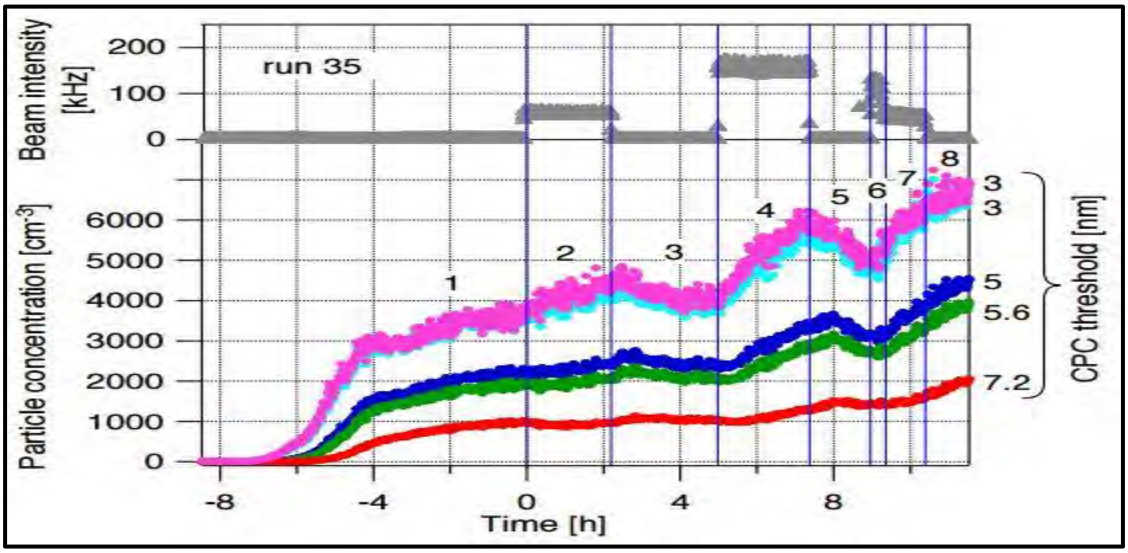


Figure 3.32 Nucleation results from CLOUD (Duplissy et al., 2010)

Further work from Svensmark (Svensmark et al., 2009) on Forbush decreases, which are sudden decreases in the CRF due to CME's, show that there is a definite connection on times-scales of days between the galactic CRF and low clouds. His pioneering work spurred questions among the wider climate community about how strong the link was between cosmic rays and climate change, which led to the 2006 cosmics leaving outdoor droplets (CLOUD) experiment at the European CERN proton synchrotron (Duplissy et al., 2010) headed by Kirkby who had done prior work on cosmic rays, but was sceptical that the link was important (Carslaw et al., 2002). The project recorded rapid aerosol formation rates in many nucleation bursts.

The CLOUD experimenters used a 3.5 GeV $_{+}$pion beam to represent the cosmic ray generated muon flux in the atmosphere, and directed it into an 8 m^3 flask containing a simulated atmosphere at variously 3 different heights. They found that the nucleation rate of sulphate aerosols in the flask increased by a factor of ten (Duplissy et al., 2010). They also found that adding ammonia (which is present in the atmosphere) increased the nucleation rate even further; ammonia seems to act as a catalyst in the process. The experiment at CERN provided empirical evidence that is 'suggestive' of a link between cosmic rays and the formation of atmospheric cloud condensation nuclei (CCN) which lead eventually to cloud formation. This presents the possibility of an amplifying mechanism for solar TSI changes existing, which is strong enough to significantly affect global temperatures, simply because of the strong effect that clouds have on albedo and that albedo has on the planetary radiative balance.

Further experimental evidence by Svensmark (Svensmark et al., 2013) has demonstrated that ionisation does assist fine aerosol growth to CCN size 50µm.

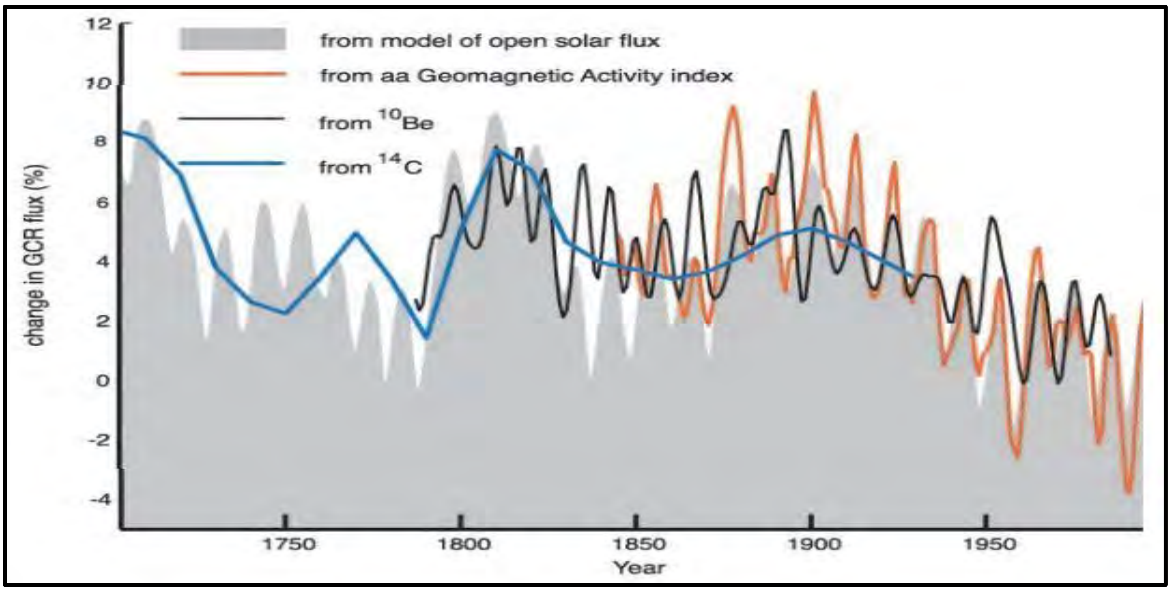


Figure 3.33 A comparison of four proxies of CRF 1700-2000 (Carslaw et al., 2002)

Figure 3.33, is a compilation of four separate CRF proxies (Carslaw et al., 2002) and shows the CRF reacting to the very large increase in solar activity which took place in the 20th century (Solanki et al., 2004).

3.5.1.17 Faint young Sun paradox can be solved without GHG

Why didn't the Earth's oceans freeze solid 4Gya, when the Sun was 30% (Hart, 1979) dimmer? Similar questions arise about Mars; how did it get to be warm enough at that time for liquid water (Forget & Pierrehumbert, 1997) to exist on the surface when it isn't now, with a much brighter Sun? Arguments have been raised in the literature, that only GHG could supply sufficient energy to the lower atmosphere to keep the Earth warm during the faint young Sun period (Foukal et al., 2006) other researchers say atmospheric changes are sufficient (Ueno et al., 2009). Other arguments have been made that high clouds alone could have kept enough heat in to keep Earth warm (Rondanelli & Lindzen, 2010) (Veizer, 2005).

These arguments sound plausible, but still do not allow for any warming effect from adiabatic auto-compression, which, if the gas partial pressure was high enough, could have provided a lot of warming to the troposphere in the Hadean-Archean termination ~3.8Gya. There is evidence that the partial pressure of combined CO_2 + N_2 was high at that time, and possibly even earlier; a calculated partial pressure of N_2 alone of ~1.2 bar (L. F. Khilyuk &

Chilingar, 2006) (Gerlich & Tscheuschner, 2009) (Sorokhtin et al., 2007) has been made. Early Earth atmospherics also contains detailed work by physicists (Gerlich & Tscheuschner, 2009) who, like Nikolov and Zeller, say that the atmospheric warmth presently associated with the greenhouse effect is in fact generated by the laws of thermodynamics and not by radiative transfer. Sorokhtin et. al. back this up with very interesting work on the early atmosphere of the Earth (Sorokhtin & Sorokhtin, 2002) (Sorokhtin et al., 2007) where they detail their explanation for solving the 'faint young Sun paradox', which does not invoke the greenhouse effect of CO_2 and CH_4 as other researchers do (Foukal et al., 2006). Instead, they argue that the young Earth had a thicker atmosphere and that the oceans did not freeze solid because the physics associated with a thicker atmosphere, leads to a warmer surface than the solar insolation might otherwise suggest. Other researchers say that it was radiogenic heat (Hoffman, Kaufman, Halverson, & Schrag, 1998) from the decay of radioactive isotopes inside the Earth which kept it warm on the surface during the period of the faint young Sun or perhaps tidal effects from the then much closer Moon (Canup, 2004).

3.5.1.18 The cyclic nature of Earth's climate

Longer-term climate cycles are caused by astronomical effects; some of these are the so-called Milankovitch cycles, which are precession; 21ky, obliquity; 41ky and eccentricity; 100ky. The current ice age is dominated by the 100ky climate cycle, and has been for a million years, before that the 41ky cycle predominated for the previous 2My (Lisiecki & Raymo, 2005). Earth is now in a deep ice age, which it descended into 3Mya, (Figure 3.34). This coincides with the Earth's entry into the Orion spiral arm segment; and

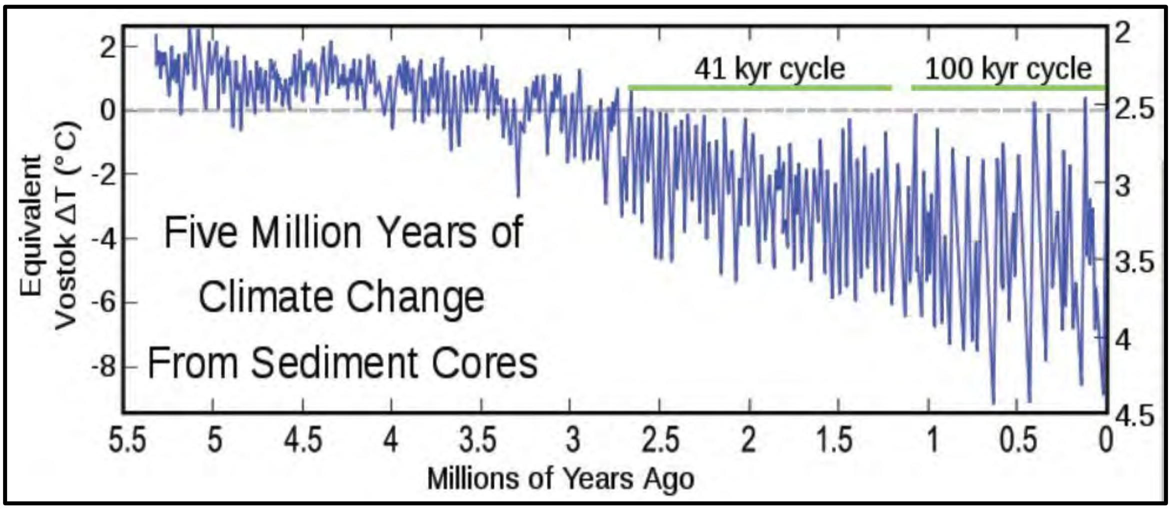


Figure 3.34 Temperature proxy ^{18}O shows 3Mya cooling into the ice age (Wiki commons)

as noted previously, several starburst events in the Milky Way. Cycles pervade the climate on all time-scales. Unfortunately, the IPCC only includes one solar or astronomically-induced climate cycle in its reports, the 11-year Schwabe sunspot cycle. This serious omission surely prevents the whole climate story from being told, since this cycle was not responsible for the observed temperature peaks in 1880, 1940 and 2000 and the observed temperature lows in 1910, and 1975 which are seen in the climate record. The culprit here, as we shall see, is the 61-year Yoshimura climate cycle (Table 3.4). Logically, the underlying natural variability caused by known climate cycles must be removed from the climate record before any possible anthropogenic effect can be successfully searched for.

3.5.2 The null hypothesis part two - adiabatic auto-compression

This hypothesis states that the reason for the difference between the effective radiating temperature of a planet, (as defined by the S-B law) and its average atmospheric near-surface temperature (Berger & Tricot, 1992) is not mainly the GHE, but another effect, referred to herein as *adiabatic auto-compression*. Although well known in engineering and physics, this effect is not so well known to climate scientists, almost all of whom are in fact either trained meteorologists or computer modellers. If auto-compression is responsible for part or all of the temperature difference, then the GHE can obviously no longer be *defined* as this difference; part or all of the difference will then have to be re-named as an atmospheric thermal enhancement. It would make little sense to retain the GHE definition, as being the ~33ºC difference, if all of it was not caused by greenhouse gases in a conventional greenhouse effect.

3.5.2.1 James Maxwell's thermodynamics equations of 1872

The origins of this effect go back to James Maxwell, who, in his 1872 book 'theory of heat' (Maxwell, 2012) demonstrated that the atmospheric temperature gradient existing from the tropopause downwards is caused by convection and more particularly, the increasing atmospheric pressure, which itself is a result of the Earth's gravitational field, and the atmospheric density.

> *"In the convective equilibrium of temperature, the absolute temperature is proportional to the pressure….." (Maxwell, 2012; p.330-331).*

In a nutshell, the adiabatic auto-compression hypothesis states that convection/pressure/lapse rate effects dominate over radiative effects in regions of all planetary atmospheres >0.1 bar (Robinson & Catling, 2014), and a consistent temperature gradient is naturally formed. What actually happens is that gravity forms a density and a temperature gradient; pressure is a corollary. (Figure 3.35) These convective regions with temperature gradients exist on all of the Solar System's planetary bodies which have thick atmospheres Robinson and Catling state;

> *"In all these bodies, the tropopause separates a stratosphere with a temperature profile that is controlled by the absorption of shortwave solar radiation, from a region below characterised by convection, weather and clouds." (Robinson & Catling, 2014).*

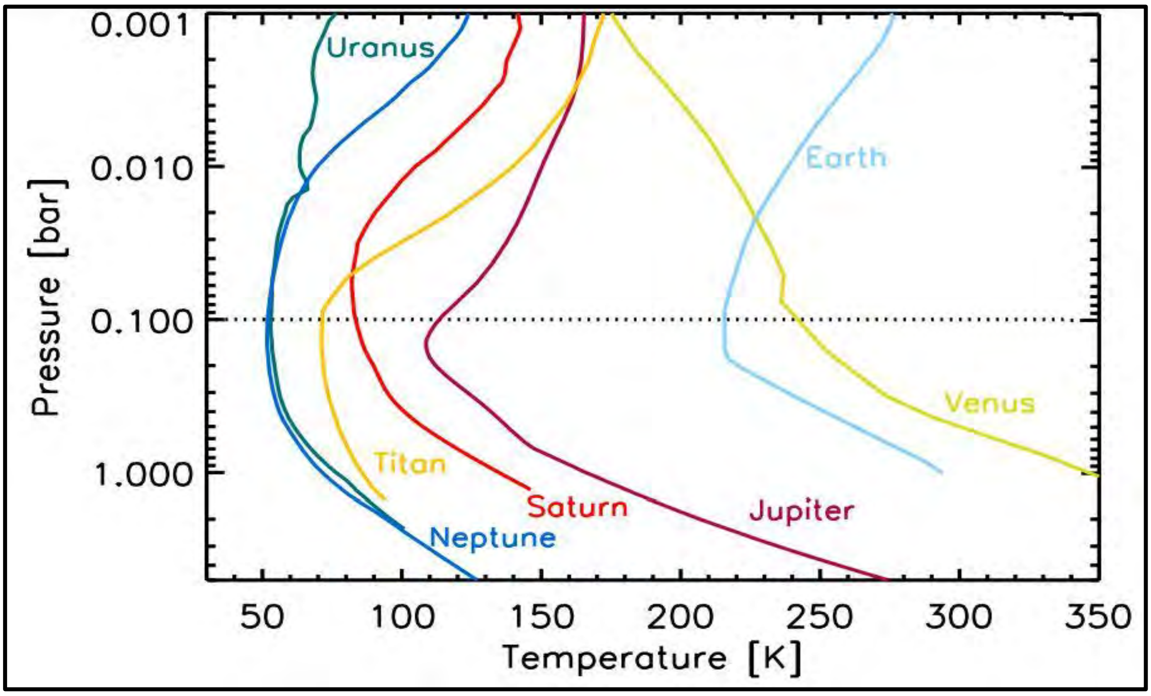


Figure 3.35 Atmospheres >0.1 bar show a thermal gradient (Robinson & Catling, 2014)

And despite vast planetary differences in insolation, internal heat, atmospheric composition and gravity, the tropopause is always around 0.1 bar of pressure. This seems to indicate that physical laws dictate for auto-compression to dominate, an atmospheric pressure of this level is required. The dominant means of energy transmission above 0.1 bar appears to be convection, while below that pressure, radiation dominates energy transfers. As can be seen (Figure 3.35) a temperature gradient is always set up at pressures of >0.1 bar. At pressures <0.1 bar, auto-compression and convection break down as the atmosphere is too thin to sustain them, and the radiative effects of GHG then predominate; but they cause *cooling* of the stratosphere and the mesosphere – not warming (Clough et al., 1995) (Figure 3.36).

3.5.2.2 *Maxwell vs Arrhenius*

As can be clearly seen, there is a strong difference between the work and the views of Maxwell and Arrhenius. Maxwell's work shows that temperatures in the lower troposphere of Earth are primarily determined by convection and the atmospheric mass/pressure/gravity relationship. Arrhenius's later work completely ignored this and determined that temperatures in the lower troposphere of Earth are caused by the radiative effects of GHG. There have been many papers critical of Arrhenius's ideas since 1909 (R. W. Wood, 1909). Who is correct is critical to the present, since if Arrhenius is correct, then there should be concern about CO_2; if Maxwell is correct, then more CO_2 will have little or no effect on tropospheric atmospheric temperatures. What do atmospheric measurements show? Measurements (Clough et al., 1995) of the effects of more CO_2 in the atmosphere appear to strongly support Maxwell; at pressures above 0.1 bar, 'the extra CO_2 merely replaces water vapour' – but at pressures below 0.1 bar more CO_2 causes strong cooling (Figure 3.36). One of the main problems with the Arrhenius view, appears to be that convection is virtually ignored as a mode of heat transfer; but later work shows that only 11% of heat transfer in the troposphere is actually carried by radiation (L. Khilyuk, 2003).

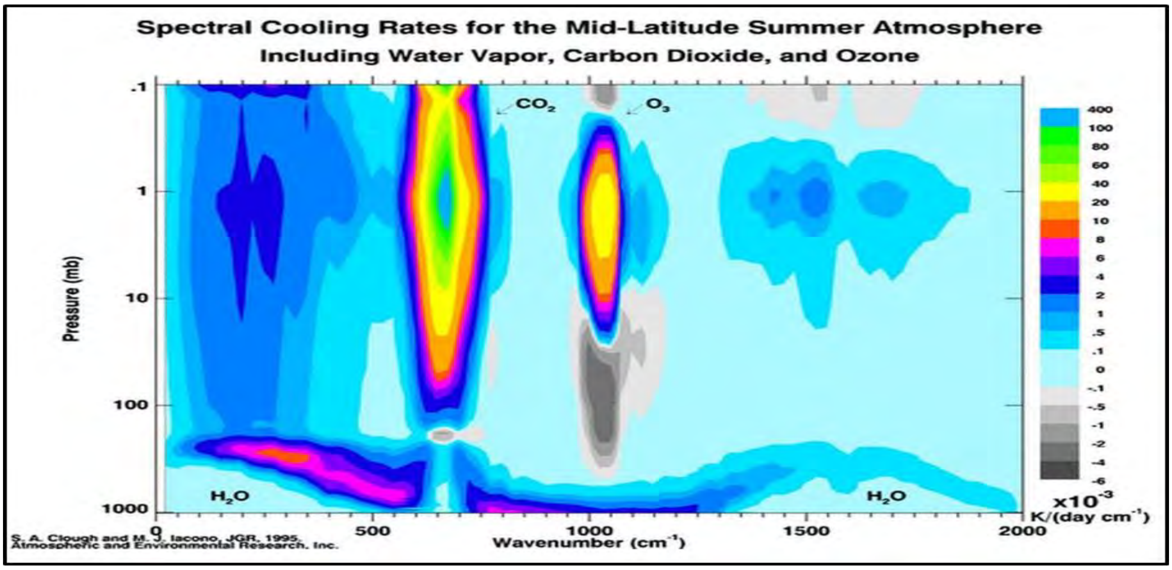


Figure 3.36 Showing cooling from CO_2 at a pressure of <0.1 bar (Clough et al., 1995)

3.5.2.3 *The special case of Venus*

The prevailing science for decades has been that the surface of Venus is very hot due to the GHE of CO_2 (J. E. Hansen, 1998; J. Houghton, 1992; Lacis, Schmidt, Rind, & Ruedy, 2010; Pollack, Toon, & Boese, 1980). Venus has an atmospheric concentration of CO_2 that is 2,400 times Earth's. The current NASA website states;

"Its thick atmosphere traps heat in a runaway greenhouse effect, making it the hottest planet in our solar system with surface temperatures hot enough to melt lead. Venus' atmosphere consists mainly of carbon dioxide, with clouds of sulfuric acid droplets. The thick atmosphere traps the Sun's heat, resulting in surface temperatures higher than 880 degrees Fahrenheit (470 degrees Celsius)."(NASA;Venus,2017)

Should Venus be regarded, as some say (Hunten, 1992), as a warning? If the Venusian atmosphere is full of CO_2, which 'traps the Sun's heat' and caused a 'runaway greenhouse effect' like NASA says on its website – leading to horrific 470°C surface temperatures (Table 3.3) – is humanity taking a risk as well, by releasing what some say are 'massive and dangerous' amounts of CO_2 into the atmosphere? A closer look at Venus is needed, its atmospheric properties, and its candidate potential for a greenhouse effect, (GHE), runaway or otherwise. In effect the question which needs to be asked is; what can be learned from Venus?

Table 3.3 Properties of Venus

Properties of Venus	
Surface temperature	+467°C / 740K
Surface pressure	9,200 kPa
Atmospheric composition	96.5% CO_2, 3.5% N_2
Wind strength surface	5 km/hr
Wind strength cloud tops	360km/hr
TOA insolation	2,644 W/m^2
Albedo	0.75
Effective radiating temperature	260°C
Effective radiating level	20km
Lapse rate	10°C/km
Density	65,000gm/ m^3
Mean moles	43.45

The first thing to note is the very high surface temperature; where did it come from, and how is it maintained – where does Venus get the energy from to keep such a heavy, thick atmosphere so hot? Looking at the atmospheric composition and the surface pressure, one thing stands out; the near-surface conditions mean that the CO_2 / N_2 atmosphere, at lower levels, can no longer be a gas but becomes a super-critical fluid. The critical pressure of CO_2 is 7,380 kPa and the critical temperature is +30°C, so the entire atmospheric surface layer on Venus to a depth of at least ~4km is a super-critical fluid. Here, five problems are readily identified with regard to the reality of the GHE of CO_2 being the cause of Venus's high surface temperatures, as is claimed by NASA;

1) The first question that might be asked is; can a highly compressed and super-heated super-critical fluid that is more like an ocean than a gas, still possess the greenhouse properties of an ordinary atmospheric gas? This seems to be unlikely. However, it is true that fermions, (of which CO_2 is made) when highly compressed, increase the width of their absorption/emission bands, (because the Pauli Exclusion Principle (Pauli, 1988) prevents fermions from being in the same state and in the same place.) Whether this factor has affected the surface super-critical fluid enough to create a gas-like greenhouse effect is unknown at present.

2) A second problem with regard to the greenhouse effect claim for Venus is that the atmosphere is very thick and is optically opaque – more like a thick soup than transparent like the Earth's atmosphere is. Measurements from the surface of Venus show that no direct solar insolation (Moroz et al., 1985) actually makes it to the surface of Venus to warm the surface for the infra-red radiation to be available to be captured in any possible atmospheric greenhouse effect. In fact, direct insolation can be neglected below a height of 60km, as all solar radiation below that level is 'scattered' by the thick atmosphere. The flux of this scattered solar insolation was measured on the surface by six separate landers, and appears to be very low (Moroz et al., 1985), averaging <<10% of the 2,644 W/m² TOA insolation flux. In contrast, Earth receives much more at 12% of its TOA insolation directly to the surface (168 W/m² of 1,366 W/m²) (Trenberth et al., 2009) and much more if scattered, atmospheric and back-radiation are counted.

3) Third, Venus has a very slow rotation period, which makes the Venusian 'night' ~58 Earth-days long (Landis et al., 2011). During this long night, measurements have been taken of the atmospheric and the surface temperatures, and they remain basically the same all through the long night just as they are during the long 58-day Venusian 'day'. The surface cools only very slightly from ~737K to ~732K during this long night. A question might reasonably be asked here; 'How can the greenhouse effect of CO_2 be responsible for all this surface heat, by trapping upwelling longwave radiation, emitted from absorbed direct solar insolation and hence keeping the surface hot with re-emitted downwelling radiation, when no direct Sun arrives to the surface during the 'day' and when no Sun at all arrives during the long 'night'?'

4) Fourth, the very high albedo reduces Venus's access to solar insolation. Even though Venus's TOA insolation is ~2x Earth's, the reflectivity of Venus is so high at 75% that this more than cancels out the higher TOA insolation. This means that although it is closer to the Sun, Venus actually receives much less Solar warmth

than Earth does; (2,644/4) x (1-0.75) = 165 W/m² vs (1,366/4) x (1-0.29) = 242 W/m² for Earth. If Venus receives even less solar radiation than the Earth does, how can it maintain a very much higher temperature profile in its atmosphere?

5) Fifth, although as might be expected because of its high density, the Venusian atmosphere moves only slowly at the surface (<10km/hr), it rotates very rapidly at height, the cloud tops level circling the planet every 4 days at speeds of up to 100m/s (360km/hr) (Svedhem, Titov, Taylor, & Witasse, 2007). It is known that the wind speed increases monotonically from very slow at the surface, upwards through the atmosphere to the cloud tops at 70km in height, where the wind speed is ~360km/hr. Why does the Venusian atmosphere rotate westwards at sixty times (Hollingsworth, Young, Schubert, Covey, & Grossman, 2007) the rotation speed of the planet, and what is the mechanism driving and maintaining it? Given that the atmosphere is in constant motion like this, how is the alleged greenhouse effect affected?

In 15 Soviet and 7 American missions to Venus (Zasova, Ignatiev, Khatuntsev, & Linkin, 2007), little difference has been found in the atmospheric temperature profiles whether investigated in the day, night, or at different latitudes (Figure 3.37). It will be noted that these multiple missions and measurements have not found any significant change in the temperature gradient as the spacecraft descends through the 4km level. This is important, since this is the height at where the density and temperature of the 96.5% CO_2 atmosphere passes the CO_2 super-criticality barrier. Below this level, all the atmospheric CO_2 becomes a supercritical fluid, and is no longer a gas; presumably no claim is being made that a super-critical fluid can still act like a common GHG. The point here is that if the GHE were indeed responsible for the observed temperature gradient and the high near-surface temperature on Venus, then surely a transition point would be visible in the gradient itself, above which the GHE is no longer in operation. In multiple measurements, such a transition is not seen (Figure 3.37). And it is known that no more than 20 W/m² of direct solar insolation arrives to the surface of Venus (Jelbring, 2003) (Moroz et al., 1985).

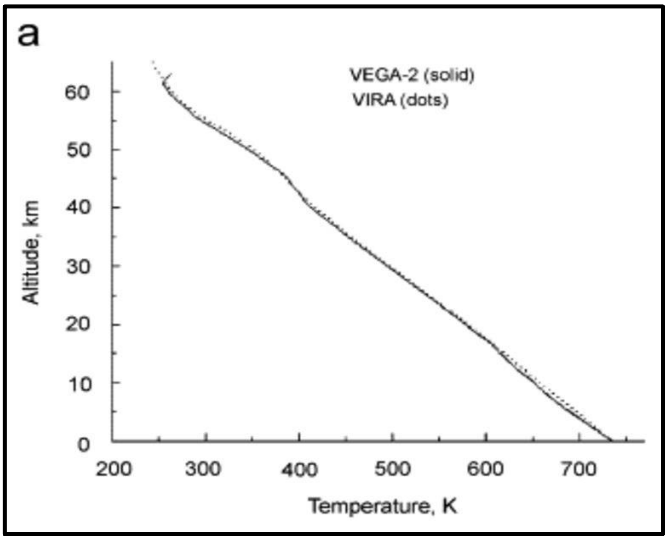


Figure 3.37 Two Venusian temperature/pressure profiles overlaid (Zasova et al., 2007)

Also of note, is that all other planetary bodies in the Solar System with thick atmospheres, possess this same uninterrupted temperature gradient at pressures above 0.1 bar (Robinson & Catling, 2014) whatever the composition of their atmosphere is. Given all these circumstances, perhaps another cause, other than the GHE of CO_2 should be looked at as a reason for Venus's scorching surface temperatures. Some researchers have already done this, (Gerlich & Tscheuschner, 2009) (Principles, Nikolov, & Zeller, 2011) and have determined that the temperature profile seen on Venus, although extreme, is merely an extension to similar temperature profiles seen on all other planetary bodies with thick atmospheres (Robinson & Catling, 2014) (Sorokhtin et al., 2007), and is not actually different in kind. And in all cases, the main cause of the temperature profile, although given different names, is thought to be the same; adiabatic auto-compression. The denser parts of the atmospheres, are all found to be dominated by a rising temperature gradient, atmospheric convection and not radiative transfer. Detailed mathematical explanations are given to support their ideas in what they call 'barometric formulas' by Gerlich and Tscheuschner (Gerlich & Tscheuschner, 2010). They claim in fact, that;

"..atmospheric CO_2 greenhouse effects have been refuted within the frame of physics (Gerlich & Tscheuschner, 2010)."

3.5.2.4 The well-known effects of auto-compression in mining

The gravity-induced pressure/temperature gradient referred to herein as adiabatic auto-compression, can be derived from Maxwell's ideal gas law and the Poisson ratio (Maxwell, 2012). It has long been known, and been taught to mining engineers, that heat in deep mines is a serious problem, and that one of the main contributors to that heat is auto-compression – a thermal gradient which is always present in a vertical column of air on Earth. This is where air, when descending in a gravitational field, essentially gets hotter all by itself – without any heat input from outside, it is therefore *adiabatic*. In mining, there is always an additional calculation for heating due to adiabatic auto-compression – where the deeper an air parcel descends, the more weight of air that there is above it, pressing down - which to simplify, essentially means that the descending mine air gets compressed by gravity. Technically, what happens is that some of the air parcel's potential energy is converted to enthalpy which produces an increase in pressure, internal energy, and consequently the temperature of the gas. This change in enthalpy is given by the steady flow energy equation;

$$(H1 - H2) = (Z1 - Z2)\ g \qquad (9)$$

H = enthalpy in J/kg
Z = height above datum metres
g = $9.8 m/s^2$

The reverse (auto-decompression) occurs when an air plume rises in a gravitational field, and as its density reduces, its potential energy increases and its temperature falls. Any gas parcel which descends in a gravitational field is heated by this well-known effect. In astronomy, it's called the Kelvin-Helmholtz (Kumar, 1963) gravitational contraction mechanism and forms a temperature gradient; examples would be adiabatic auto-compression of air on Earth, cold molecular gas clouds collapsing to form a proto-star in inter-stellar space, or the atmospheric temperature gradient on Venus (Figure 3.37).

A rule now can be followed; that whenever any gas flows downward in a gravitational field, some of its potential energy is converted to enthalpy, producing an increase in pressure, internal energy and temperature; and the amount of this conversion can be calculated according to the following formula;

$$H = PV + U \text{ (in Joules/kg)} \qquad (10)$$

Where;
H is enthalpy
P is pressure
V is volume
U is specific internal energy

This gas can be air or CO_2 - the composition of the gas does not matter. The downward flow, and the commensurate upward flow in a troposphere can be described as convection. The properties mentioned above are all thermodynamic properties of state, and therefore enthalpy must be also. No external heat input is assumed or needed during the descent; the descending gas will heat up. Why does the gas heat up? Because potential energy is converted to enthalpy as the gas is compressed - essentially by gravity. To extend this line of thought, it can now be said that a *thermal gradient* is always formed in a thick atmosphere compressed by a gravitational field, in accordance with this equation;

$$Td/H = g/Cp \tag{11}$$

Where;

Td	the temperature differential (or lapse rate 9.8 K/km)
H	the height differential (km)
g	acceleration due to gravity (9.8076 m/s²)
Cp	specific heat of the atmosphere (Joule/kg/Kelvin)

For example;

$$9.8/1 = 9.8076/Cp$$
$$9.8 = 9.8076/Cp$$
$$Cp = 9.8076/9.8$$
$$Cp = {\sim}1.001$$

It can immediately be seen that the *rate* of warming depends on two things; the strength of the gravitational field and the heat properties of the atmosphere. When a gas is compressed, it does negative work and its temperature rises. James Maxwell detailed the Poisson relation, (derived from the ideal gas law) and can be represented using this formula, by which the increase in pressure as gas descends in a gravitational field can be calculated;

$$Pe = Ps \exp(gH/RT) \tag{12}$$

Where;

Pe	absolute pressure at end of column in kPa
Ps	absolute pressure at start of column in kPa
g	9.8 m/s² acceleration due to gravity
H	vertical depth in metres
R	287 average temperature on Earth in Kelvin
T	temperature of gas in Kelvin

The increasing mass of air above the descending air parcel, compresses the air parcel as it descends; during this process, some of the parcel's gravitational potential energy is essentially converted to heat. During this process on Earth, a dry air parcel will warm up at the rate of 0.976°C per 100m of fall (Dumas, 2013). This effect is often termed; 'adiabatic auto-compression' in engineering circles, or the 'dry adiabatic lapse rate' in climate circles.

The process of a gas expanding and contracting without exchanging heat externally is called an adiabatic process.

Note that although any atmospheric parcel which is already >10 kPa, does heat up as it descends in a gravitational field, and cools as it rises again in the same field, so forming a natural thermal gradient, a similar thermal gradient forms due to this effect – even in a still atmosphere. Convection itself is not a requirement of the thermodynamic process which forms this thermal gradient. The idea of a thermal gradient naturally forming in any column of gas in a gravitational field was first proposed in the 1860's by Loschmidt (Flamm, 1997). At the time, Maxwell thought that this idea violated the second law of thermodynamics, yet as has been seen, derivations of Maxwell's own ideal gas law is an excellent predictor of temperatures – when compressed by a gravitational field. The controversy between Loschmidt on one side, with Maxwell and Boltzmann on the other, raged for some time and was finally experimentally tested in 2007, with the results published by Graeff (Graeff, 2007). Graeff's experiments concluded that a gravitationally-induced temperature gradient does spontaneously develop in sealed columns of both air and water – the bottom of the column being warmer than the top. The theoretical amounts of warming according to Loschmidt should be 0.07K/m and 0.04K/m respectively. Graeff's experimental apparatus reported 0.07K/m and 0.05K/m – so basically confirming Loschmidt's predictions, and the gradient appeared despite the reverse gradient being prevalent in the immediate environment of the experiment. Loschmidt believed that the second law needed to be re-stated to include the effects of gravitational fields on fluids.

3.5.2.5 Auto-compression and star formation

Adiabatic auto-compression and it's heating effect, where gravitational potential energy is converted to kinetic energy, is well known in astronomy, specifically in the formation of protostars (Zinnecker & Yorke, 2007). This is essentially what causes the interstellar cold molecular gas to heat up as it collapses gravitationally (Larson, 1969) to form a proto-stellar disk and finally into a star, this takes millions of years and in the latter stages, the Kelvin-Helmholtz (Kumar, 1963) contraction allows temperatures to reach millions of degrees – hot enough for nuclear fusion to initiate. What stops further collapse is a combination of angular momentum and when the gas is hot enough for its internal pressure to prevent further collapse, or it becomes optically thick; then a state called 'hydrostatic equilibrium' is temporarily reached.

3.5.2.6 *What is temperature?*

Temperature is a measure of the mean kinetic energy of all the molecules in the place measured. As has been seen, a column of gas in a gravitational ‘field’ is affected in such a way as to create the conditions which causes the gas to be warmer at the bottom than it is at the top. In effect, how this is done is that the field *redistributes* the kinetic and the potential energy contained in the gas in such a way, as to form a kinetic energy gradient in the column – with more at the bottom and less at the top. This can be viewed as how a gravitational well causes the gas to take on the form of the greatest entropy; by having less kinetic energy at the top and more at the bottom. Bear in mind the true nature of gravity itself here; it is not a force, but is simply a curvature of space-time that is formed by the presence of a mass such as the Earth. Like all material things moving unhindered in space, gas naturally flows on a geodesic down the indentation in space-time in the vicinity of the Earth, until it is stopped by a greater force, which is in this case the ‘solid’ surface of the planet; gravity is not a force and does not actually ‘attract’ anything. A parcel of gas moving ‘down’ in a gravitational field, must lose an amount of potential energy equal to;

$$\text{Loss of Pe} = M.g.H$$

Where;

M	mass of parcel
g	gravity
H	height reduction

The potential energy loss will be replaced by a gain in kinetic energy equal to;

$$\text{Gain in Ke} = M.Cp.Tg \tag{13}$$

Where;

Cp	specific heat
Tg	temperature gain

So;
$$M.Cp.Tg = -M.g.H \tag{14}$$

And;
$$Tg/H = -g/Cp \tag{15}$$

This makes Tg/H the thermal gradient - which does not need motion; it can be static. In effect, a state of near-hydrostatic equilibrium is what exists on Earth in the troposphere – and on other Solar System bodies which have sufficient near-surface, gravity-induced gas pressure to generate convection and substantial auto-compression. That particular pressure level has been shown to be >0.1 bar (or >10 kPa) (Robinson & Catling, 2014).

3.5.2.7 Adiabatic expansion and compression – a summary

- When a gas expands adiabatically it does positive work
- The internal energy drops and the temperature drops
- When gas is compressed adiabatically it does negative work and the temperature rises
- Temperature is the measure of kinetic energy of chaotic motion of the molecules
- Higher temperatures correspond to more intense motion of the gas molecules

Since the atmospheric pressure decreases with altitude, the volume of an air parcel expands as it rises. Conversely, if a parcel of air sinks from a higher altitude to a lower altitude, its volume is compressed, and density rises. An adiabatic lapse rate is the rate at which the temperature of an air parcel changes in response to the expansion or compression process associated with a change in altitude, under the assumption that the process is adiabatic (i.e. no heat is added or lost externally during the process).

A question arises; Can an entire atmosphere be considered subject to adiabatic auto-compression – and hence be warmer at the surface than expected from a calculation based on the S-B law? The fact is that when the greenhouse effect (Schmidt et al., 2010) has been calculated to be 33°C, no allowance is made for the effects of adiabatic auto-compression. Complicating matters further, the Earth is not a perfect black body, and so has an emissivity of <1. A perfect black body is one which absorbs all the radiation which falls upon it, and when in thermal equilibrium, emits electromagnetic radiation according to Planck's law, (Planck, 1900) in the form of a spectrum curve the intensity of which depends on temperature alone. The Sun and the Earth act as grey bodies, but their emissions curves are reasonably close approximations of a black body emission spectrum (Figure 3.38). The Sun has a radiative intensity peak of approximately 3.5 x 10^6 times greater than Earth's due to the higher surface temperature of ~6,000K as opposed to Earth's ~288K.

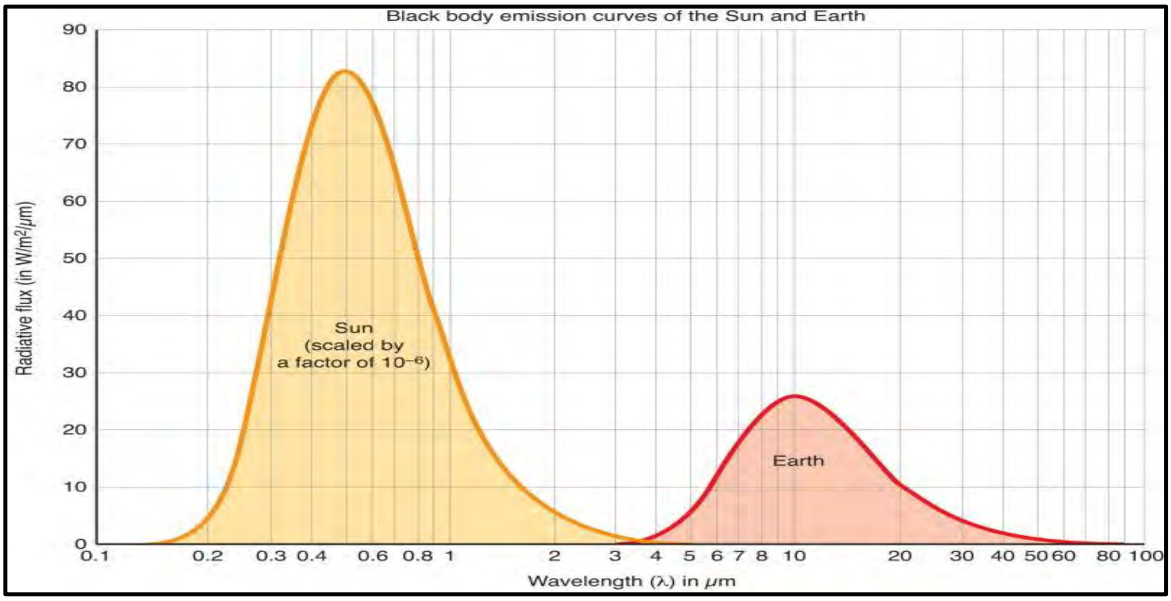


Figure 3.38 Emission curves of the Sun and the Earth (American Chemical, 2017)

3.5.2.8 *The 'greenhouse effect' recalculated*

What if the warming attributed to greenhouse gases were, in reality, to be much lower than the 33°C than has been thought to be the case for many decades? This surely would immediately affect the climate sensitivity to CO_2, since if CO_2 is 20% (Schmidt et al., 2010) of the greenhouse effect, then 20% of a much smaller figure must reduce the warming effect of atmospheric CO_2 in a commensurate way.

But how could this possibly be wrong? It is known that there is a lot more heat in the lower atmosphere than there should be from solar insolation alone; it can be measured both at night and during the day. There is some confidence about the reality of the global energy budget (J. T. Kiehl & Trenberth, 1997) and certainly of the reality of the downward longwave flux (Morcrette, 2002) because this has been measured. The validity of the S-B law has hardly been questioned, and that the radiating temperature of an Earth with a 29% albedo but without an atmosphere would be 255.7K. Albedo is powerful; just a 1% change in albedo puts a greater forcing on the climate system than the IPCC's estimated cumulative effect of all the anthropogenic forcing's since 1750.

What is found, is a lot of heat in the lower atmosphere, which is unexplained without the effect of GHG – or is it? What if that heat is really there, but is not mainly caused by GHG such as H_2O, CO_2 and CH_4 trapping escaping infra-red radiation? Could this heat source be adiabatic auto-compression? Just how much warming should be expected from this heat source, if it does strongly affect the troposphere? To recap;

- the dry adiabatic lapse rate, 0.0098K/m (equivalent to 9.8K/km)
- Earth's gravitational acceleration, 9.8076 m/s²
- the specific heat of dry air at constant pressure, 1004.64 J/(kg K)
- the dry adiabatic lapse rate is approximately constant in the troposphere
- in this case, 'dry' air means unsaturated air, it may contain some water vapour
- convection predominates up to a pressure of 0.1 bar – the tropopause
- the tropopause is where the lapse rate decreases rapidly, and becomes negative
- the tropopause is higher at the equator than at the poles

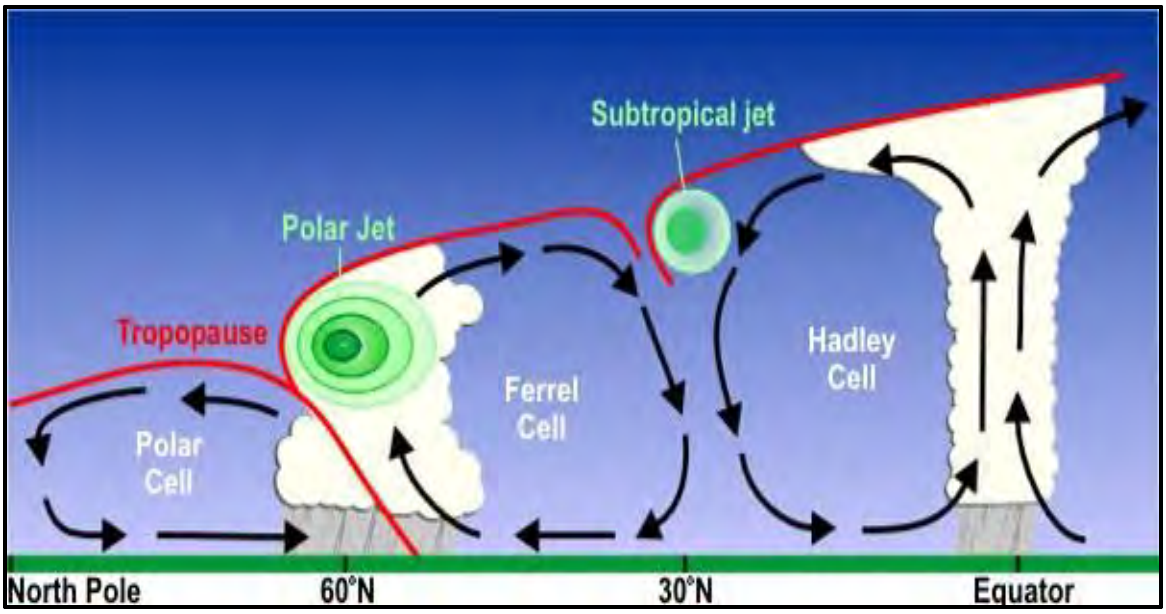


Figure 3.39 Cells are higher (17km) at the equator than (9km) the poles (Petty, 2008)

An unsaturated parcel of air (Figure 3.39) will rise from Earth's surface and cool at the dry adiabatic rate of – 9.8K/kilometre until it has cooled to the temperature, known as the atmospheric dew point, at which the water vapour it contains begins to condense (i.e., change phase from vapour to liquid) and release the latent heat of vaporization. At that dew point temperature, the air parcel is saturated and, because of the release of the heat of vaporization, the rate of cooling will decrease to what is known as the wet adiabatic lapse rate. The wet adiabatic lapse rate can vary from about 4K/km in regions where the ambient temperature is about 25°C to about 7K/km in regions where the ambient temperature is about -10°C. In the troposphere as a whole, the lapse rate averages 6.5°C/km (Petty, 2008).

At the poles, the warming is more there per km, but the troposphere is also thinner; and so the net warming effect through the troposphere then becomes similar in different regions.

The international civil aviation organization defines an international standard atmosphere as having a lapse rate of 6.49K/km. Polar regions have little convection, and instead are dominated by a negative radiation balance and jet streams. Occasionally, with some polar weather polar patterns, the tropopause drops down to 5km, which provides a figure to work from for the action of convection. If the minimum height of the troposphere is taken to be 5km and the auto-compression rate to be the same as the standard lapse rate, then the potential average warming at ground level due to auto-compression is:

$$\sim 5 \times \sim 6.49 = \sim 32.5°C$$

As can be seen from these figures, the potential surface air temperature warming due to adiabatic auto-compression is similar to the putative greenhouse effect thought to be associated with these trace dipole gases. It is conceivable that the troposphere's greenhouse effect may be partially or completely overcome by auto-compression and convection. Complicating matters are other atmospheric processes such as the release of latent heat, rising monsoon and thunder heads, radiation through the atmospheric window; these all have a significant cooling effect on near-surface atmospheric temperatures. Low clouds can in some cases restrict the height that convective processes achieve, restricting their effect. Clouds typically cover over 60% of the Earth's surface, and could well also form a limiting height, slowing convection and the processes associated with it if they are low.

Above the tropopause, radiative effects predominate; but in the stratosphere and the mesosphere there is very little water vapour which leaves CO_2 and O_3 as the main 'greenhouse' gases. However, their effect in this part of the atmosphere is not to provide greenhouse warming (Figure 3.36), instead their radiative action provides cooling (Clough et al., 1995).

3.5.2.9 The logarithmic nature of the greenhouse effect of CO_2

The greenhouse effect of CO_2 is logarithmic (Ramanathan & Vogelmann, 1997) (Lindzen & Choi, 2009). In practice, this means that each additional ppm added to the atmosphere has less effect than the last ppm added; in fact a very large portion of the warming from CO_2 actually comes from the first 20ppm (Figure 3.40) (Lindzen & Choi, 2009). The greenhouse effect of CO_2 can be likened to painting a window white to block out the Sun; additional coats after the first one, only have a small effect. The nature of the greenhouse effect of other greenhouses gases, such as H_2O and CH_4, however, is not logarithmic.

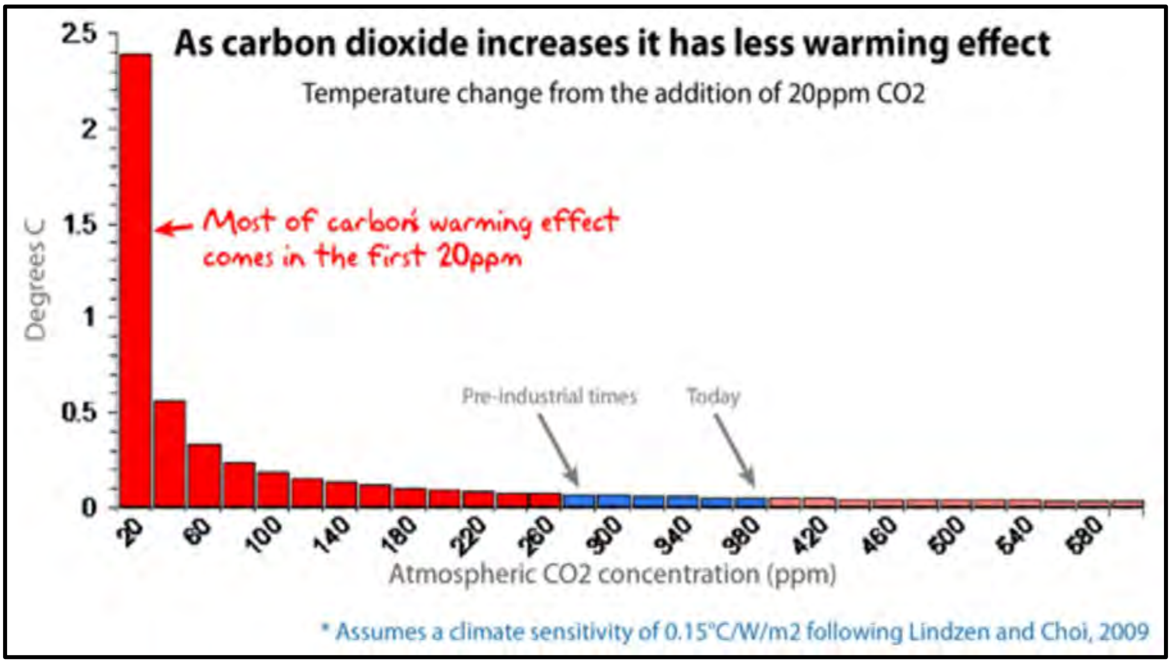


Figure 3.40 The logarithmic effect of the GHG CO_2 (Lindzen & Choi, 2009)

3.5.2.10 The benefits of global warming

Something that is almost never mentioned in IPCC reports are the *benefits* of global warming; and some of these benefits come directly from the presently enriched state of atmospheric CO_2. These benefits are extensive, and include greater foodstuffs production, which have allowed an extra 500 million people to be fed (Bjørn Lomborg, 2007) than would otherwise be the case; less deaths due to cold weather (Gasparrini et al., 2015), and increased vegetation growth. In experiments, doubling CO_2 levels has been measured to increase plant growth by around 30% (S. Idso, Kimball, Anderson, & Mauney, 1987). And in the real atmosphere, an 11 per cent increase in global foliage cover 1982-2010 has been discovered by the CSIRO; growth was particularly robust in Africa's Sahel, India and in Australia. This phenomenon has been called 'the greening of the Earth' (Donohue, Roderick, McVicar, & Farquhar, 2013) it has been effective in shrinking deserts.

Another feature of warmer global temperatures is less storminess and wild weather (Weisse, von Storch, & Feser, 2005). A warming climate means a lowering temperature differential between the equator and the North Pole, a change which theory and data, show reduces the frequency and intensity of hurricanes and cyclones.

3.5.3 The null hypothesis part three - cyclic climate drivers

Table 3.4 Climate cycles found in the scientific literature

Cycle years	Climate cycle	Related & probable cause of climate cycle
9.1	Lunar	Moon’s orbital cycles
11	Schwabe	Sunspot cycle
22	Hale	Magnetic field reversal on the Sun cycle
61	Yoshimura	Sun’s barycentre / Jupiter-Saturn resonance
84 - 92	Gleissberg	Solar activity related to Uranus orbital period
120	Velasco	Predicts solar minimum in 2040
172	Landscheidt	Uranus-Neptune synodic period resonance
210 - 240	De-Vries / Suess	TSI cycle linked via 5/2 resonance to Uranus
934	Bond /Eddy	Angular momentum - sum of planets and Sun
1,470	Dansgaard-Oeschger	Not known – found through Heinrich events
2,300	Hallstatt / Bray	Solar cycle
26,000	Milankovitch	Precession cycle of the Earth’s axis
41,000	Milankovitch	Obliquity cycle of the Earth’s axial tilt
100,000	Milankovitch	Eccentricity cycle; changes in Earth’s orbit
32,000,000	Not named yet	Sun’s vertical oscillation through Milky Way
141,000,000	Not named yet	Sun traverses Milky Way’s spiral arms

Very many regular climate cycles are found in the literature. Most if not all of them have been found to have an astronomical origin, the decadal or centennial ones being related to solar or planetary cycles, the millennial ones being associated with changes in the Earth’s axis or orbital eccentricity. Other, much longer climate cycles have recently been discovered by astrophysicist Nir Shaviv and Jan Veizer which seem to be related through long-term cloud changes to the flux of galactic cosmic rays. These climate cycles collectively form the basis of what might be termed the natural variability that is behind the null hypothesis. Of most concern to humanity are of course those which are affecting the climate now, and these are the cycles of Dansgaard-Oeschger length or shorter (Schulz, 2002). Interestingly, the Gleissberg cycle, seen often in temperature and tropical reconstructions, is missing at the poles (Velasco, Mendoza, & Valdes-Galicia, 2008). Instead, other climate cycles, such as the Yoshimura and De-Vries seem to predominate in those regions. Mention needs to be made of the long-term changes that the Sun is known to undergo (Foukal et al., 2006) and the occasional, random outbursts of GCR to which Earth is subjected, and appear to coincide with sudden and dramatic climate changes on Earth (Kataoka et al., 2013).

3.5.3.1 Cycles dominate the last few thousand years; cycles are in GISP2

Work by Humlum et. al. (Humlum et al., 2011) on the last 4ky of the deep Greenland ice core GISP2 reconstructed temperature series, has identified three persistent centennial to millennial-scale cycles of natural variability, using Fourier and wavelet transforms. Using a combination of three of the natural cycles found in this data (the 2,800 1,190 and 560 year) a model was developed and used to hind-cast and forecast the GISP2 temperature series. These particular cycles must be of astronomical origin, but still seem to be stronger at the poles than in other places (Yndestad, 2003) (Figure 3.41). The modelled line, (in green) had a coefficient of determination of 0.63 for the hindcasting period and the current warm period (CWP) is also well represented. There is agreement between this and other work (H-J Lüdecke et al., 2013) that natural climate cycles played a large part in the general global warming that has been recorded since the LIA bottomed out in 1690. However, it must be noted that trends in the temperatures of central Greenland are not necessarily identical to trends in the global temperatures, nevertheless there are strong similarities.

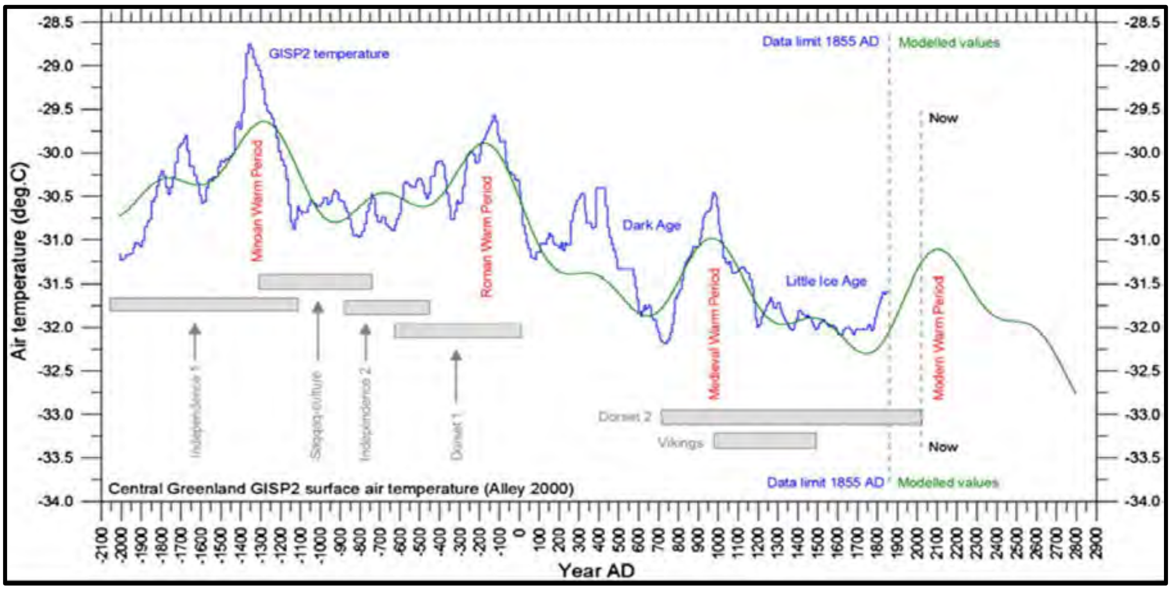


Figure 3.41 GISP2 temperatures (blue) against a 3-cycle model (green) (Alley, 2000)

More support for a mainly solar-induced warming comes from Stauning (Stauning, 2013). He concludes that all the warming up to 1990 can be explained by the Sun. The warming seen after 1990 then presumably in not all the Sun; however, Staunning does not allow for the clearing of the atmosphere after the Pinatubo eruption. It is clear in the data that Pinatubo caused a significant ~0.3°C of global cooling for 2-3 years. He also does not allow for the effects of known climate cycles, such as the peaking of the Yoshimura in 2002 and the De-Vries around 2000. If the natural 1991 Pinatubo eruption and its associated aerosol global cooling is ignored, satellite and balloon data show that little or no global warming has occurred in the lower troposphere since 1990; for example, the 2km global measurements from NASA's TRIOS-N satellite, as compiled by UAH MSU (Figure 3.98) show the current (2017) anomaly is +0.3°C, just as it was in 1990.

The climate cycles which seem to be most relevant to the current topic of climate change are firstly the Yoshimura, then the Bond and finally the De-Vries/Suess. The Hallstatt is a longer cycle (Ma, 2007) and although it seems to be related to grand minima clusters such as the Oort, Wolf, Sporer, Maunder and Dalton (Nussbaumer et al., 2011), it is not relevant to the multi-decadal climate changes that are of immediate concern; however, from the ^{14}C proxy record, it is known that the Hallstatt is near a maximum currently (Clilverd, Clarke, Rishbeth, Clark, & Ulich, 2003). It is unfortunate that only one of the 16 known (Table 3.4) climate cycles (the Schwabe) has to date been quantified and included in the IPCC's reports as to its effect on the climate system, because as will be shown, these known climate cycles dominate the climate record on all time-scales, including during the last century.

Figure 3.42 depicts a multi-proxy reconstruction of the extra-tropical Northern Hemisphere over the last 2ky (Ljungqvist, 2010). The timing of the warm and the cold periods agrees both with other reconstructions (Moberg, Sonechkin, Holmgren, Datsenko, & Karlén, 2005) (Loehle, 2007) (Kaniewski et al., 2011) and with recorded and well-known historical climatic periods. The Roman warm period (RWP), the dark ages (DA), the medieval warm period (MWP), the little ice age (LIA) and the current warm period (CWP) are all well represented. The three warm periods are all at a similar level, (Abbot & Marohasy, 2017). the DA was ~0.7°C cooler than now and the LIA was ~0.9°C cooler than now. Prominent in this reconstruction is the ~934-year Bond cycle; but the underlying longer-term trend in the Holocene is towards cooling (Marcott et al., 2013) (Rosenthal, Linsley, & Oppo, 2013) (H. Zhang et al., 2015).

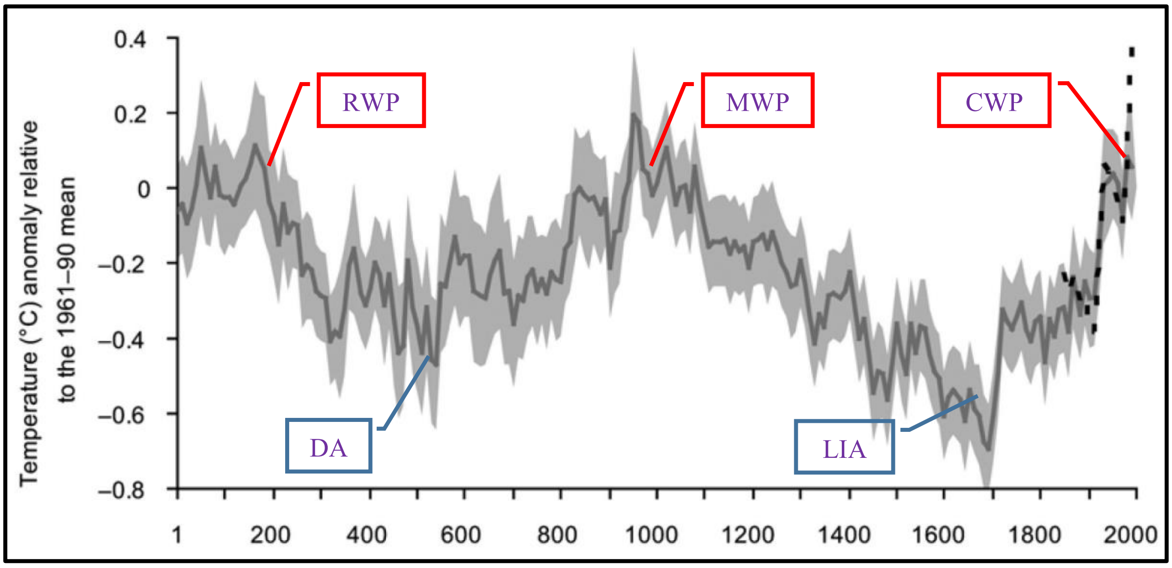


Figure 3.42 Extra-tropical N.H. temperature variability (Ljungqvist, 2010)

3.5.3.2 Orbital resonances of the Sun and planets

Extensive and detailed work on the interaction and resonances of the Sun and planets (Semi, 2009) has resulted in Figure 3.43, which shows the Bond cycle over the last 4ky and Figure 3.44, which is the clipped scalar sum of the angular momentum of the planets and the Sun. Planetary orbital synchronisation is also a feature of the Solar System, for example the Uranus-Neptune synodic period resonance, and these periodic synchronicities appear strongly in the climate change record (Table 3.4) (Scafetta, 2014)

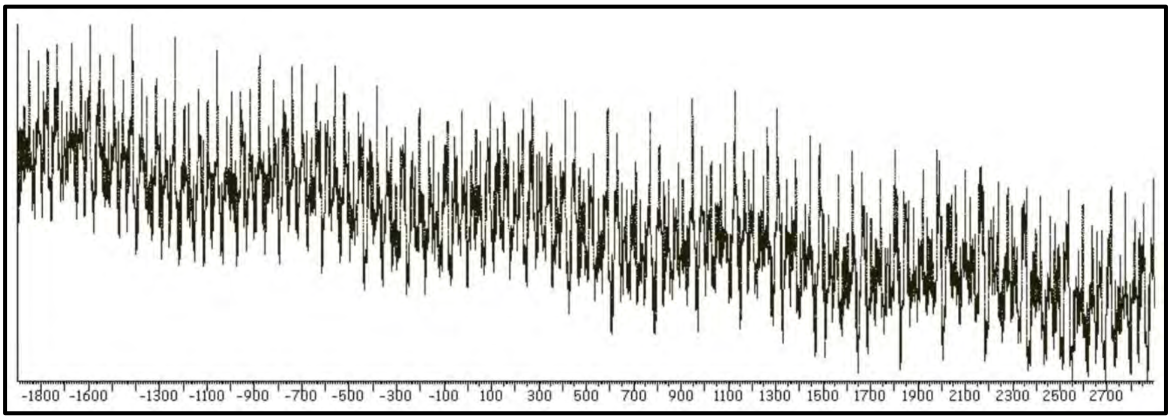


Figure 3.43 Orbital resonances of the planets shows a declining 1ky cycle (Semi, 2009)

The ~1ky cycle in Figure 3.45 correlates quite well with known Bond cycle climate changes on Earth. The overall descending trend also correlates with the declining temperature trend during the latter half of the Holocene (Alley, 2000) (Rosenthal et al., 2013).

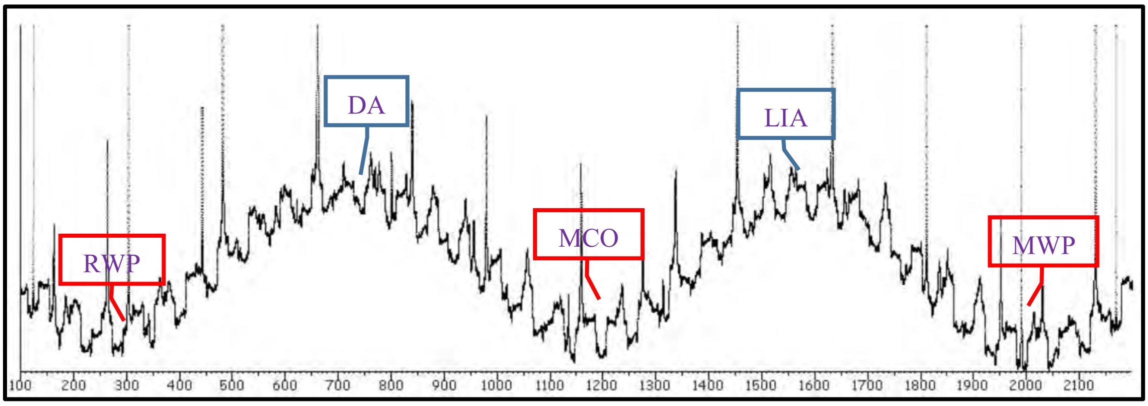


Figure 3.44 Clipped scalar sum, angular momentum of the planets and Sun (Semi, 2009)

When Figure 3.44 is inverted and compared to proxy reconstructions of climate changes over the same period, a very close correlation is observed. Again, the same ~934-year Bond climate cycle is seen, and when examined closely, (Figure 3.15) the ~61-year Yoshimura climate cycle that is very prominent in many climate records is also clearly visible. Even the longer-term Holocene decline in global temperatures, can be seen here, and matches the decline seen in the GISP2 ice core proxy data (Marcott et al., 2013).

3.5.3.3 Climate cycles also dominate the last few hundred years

The 61-year Yoshimura cycle is associated with known warm peaks in 1880, 1941 and 2002; further warm peaks are predicted for 2063 and 2124 (Figure 3.45).

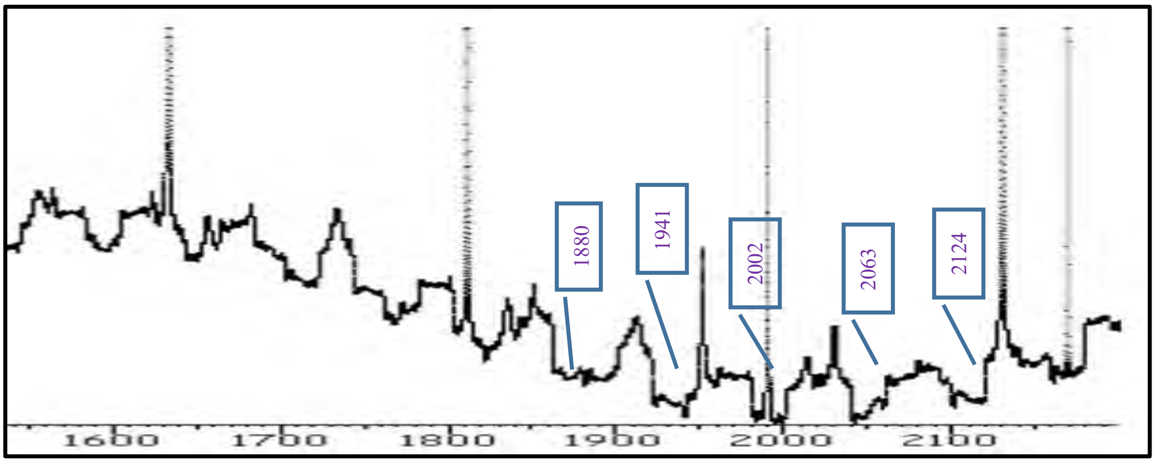


Figure 3.45 Detail last 500 years of solar and planetary angular momentum (Semi, 2009)

The converse cold troughs associated with this cycle were in 1910 and 1971, with another cold trough predicted in 2032. Most or all of the 1971 – 2002 measured rise in global temperatures appear to be mainly related to this climate cycle (H-J Lüdecke et al., 2015); in any event, no substantial difference can be seen (Green & Armstrong, 2014) between the rate or the extent of the 1971 - 2002 rise and the 1910 – 1940 rise in global temperatures, both are closely associated with consecutive upswings in the Yoshimura climate cycle. In fact, when compared to a 60-year modulation, the cycle is much better seen and a close similarity appears between these two upswings when they are detrended, turned into an 8-year moving average and shifted 61.5 years (Scafetta, 2010). The longer Bond cycle, the middle Suess cycle and the shorter Yoshimura cycle are all peaking at present, and when projected, all show a cooling trend starting soon, however, this does not take into account any possible future anthropogenic warming.

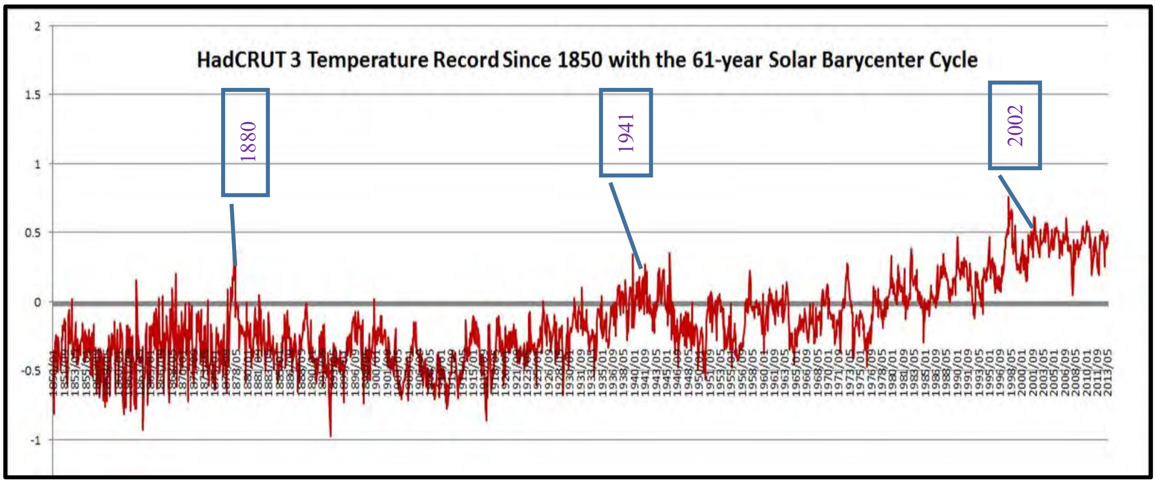


Figure 3.46 61-year climate cycle (Brohan, Kennedy, Harris, Tett, & Jones, 2006)

Presented here in Figure 3.46 is the U.K.'s Hadley centre/climate research unit's global surface temperature record 1850 – 2014 known as HadCRUT3 (Brohan et al., 2006). Clearly shown are the peaks in the 61-year Yoshimura climate cycle. It is also seen in other multi-decadal climatic changes on Earth, such as the Atlantic Decadal Oscillation (AMO) and the Pacific Decadal Oscillation (PDO). (Figure 3.48) (Columbia University, 2017). The HadCRUT4 series has been plotted as a 50-year trend (Figure 3,47) which more clearly reveals the 61-year Yoshimura climate cycle that exists in the data.

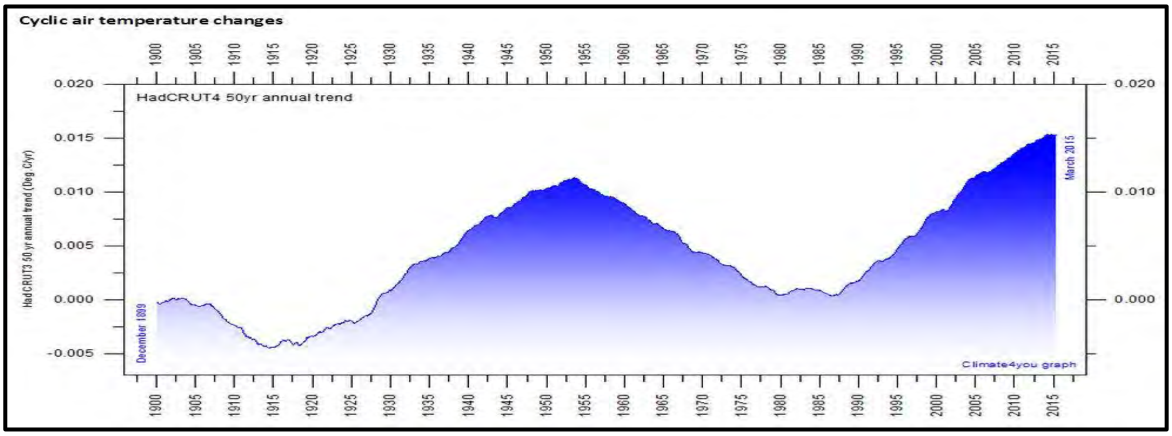


Figure 3.47 HadCRUT4 50-year linear trend shows the ~61-year cycle (Climate4you50)

As can be seen, the ~61-year Yoshimura climate cycle (Yoshimura, 1979) is one of the most important decadal climate cycles seen in the climate system when considering recent climate change. It dominates the temperature trend in the 20th century. Taking it into account when assessing the speed and range of recent natural decadal climate variability is obviously essential, yet surprisingly it is not assessed nor quantified in any of the IPCC's five major climate change reports.

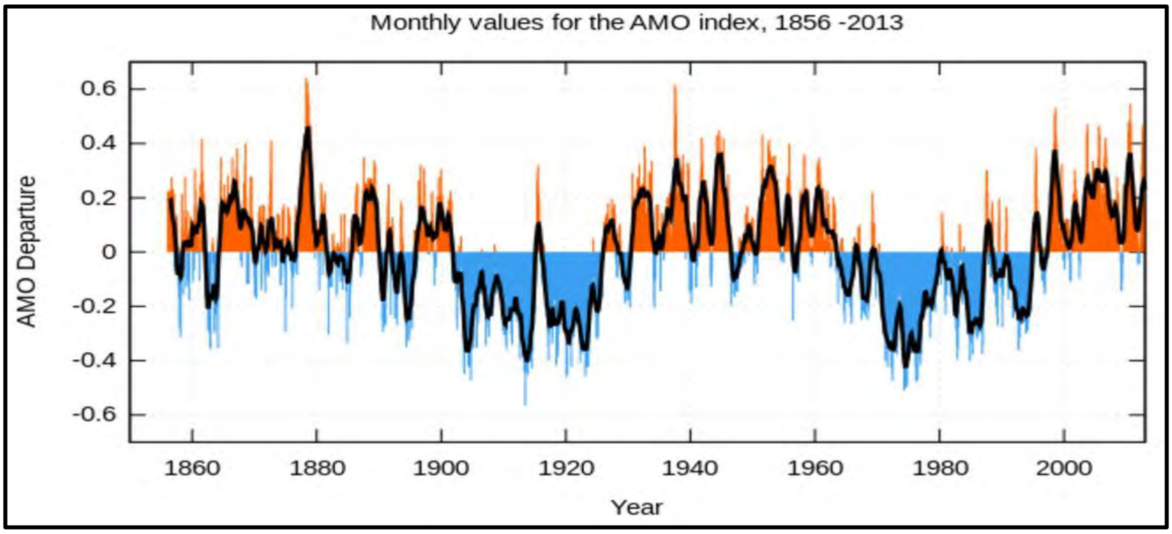


Figure 3.48 Atlantic multi-decadal oscillation (AMO) Columbia (WikiCommonsAMO)

A Fourier analysis of accumulated cyclonic energy of duration <100yr in the Atlantic reveal the Yoshimura prominently (Figure 3.49) (Humlum, Solheim, & Stordahl, 2012). In a statistical sense, only the 61-year cycle is significant and indicates along with other data, that the ~61-year cycle is a deeply embedded feature of the climate system.

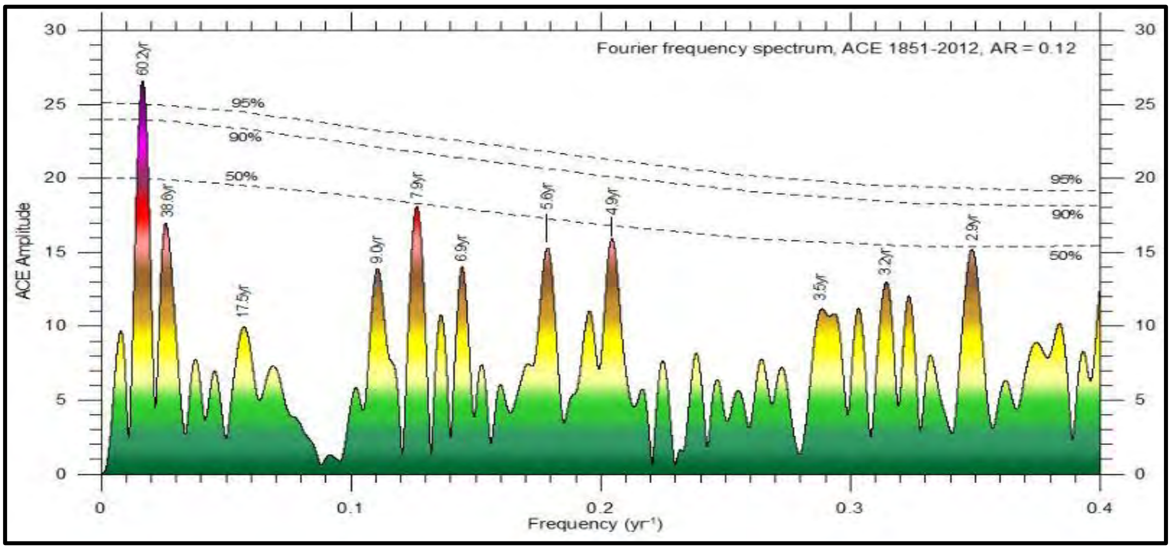


Figure 3.49 Fourier analysis of storm cycles in the Atlantic (Humlum et al., 2012)

3.5.3.4 Long term records from six European cities show cyclic behaviour

In an examination of the longest climate records in Europe, six cities were found to have excellent long-term temperature series, going back to 1757; all show a ‘V’ shape but no overall trend (H-J Lüdecke et al., 2013) (Figure 3.50). When the data was subjected to harmonic decomposition, five dominant cycles of >30years appeared; 248, 80, 61, 47 & 34.

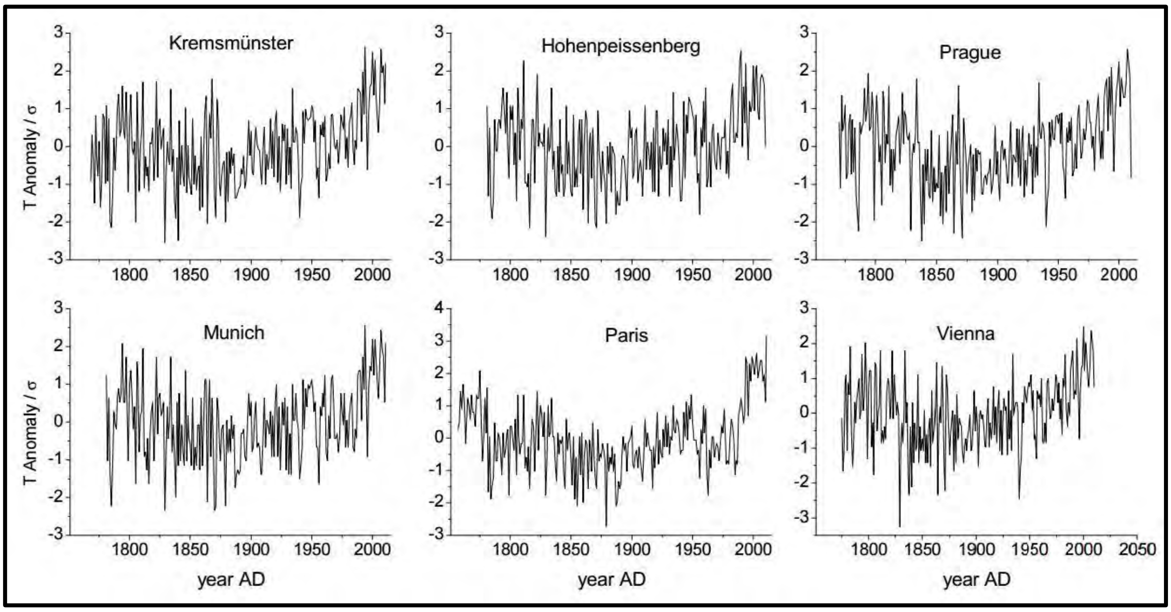


Figure 3.50 Six cities since 1757 show no temperature trend (H-J Lüdecke et al., 2013)

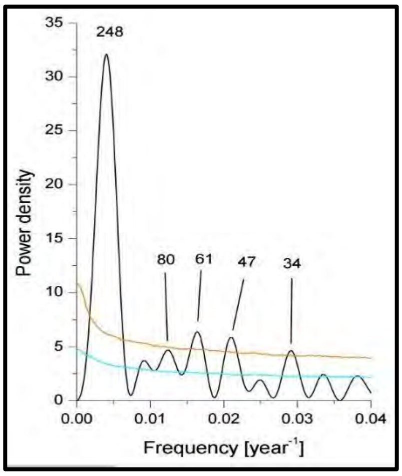


Figure 3.51 The European city data reveals five climate cycles (H-J Lüdecke et al., 2013)

It will be seen in Table 3.4 that the longer three climate cycles are well known from other work, and are the De-Vries, Gleissberg and Yoshimura respectively (Figure 3.51). The existence of these climate oscillations globally, was confirmed by the authors taking anomalies from a stalagmite record and a longer Antarctic ice core record. A 15-year running boxcar average of the mean of the six cities was compared to a combination of the main climate cycles found in the data series (Figure 3.52). An agreement of r = 0.961 was found. This agreement shows that the climate is dominated by these few cycles at present; a projection forwards (dotted line) predicts a fall in temperatures between now and 2050, this mainly caused by the cyclic down-turn of the 61-year Yoshimura.

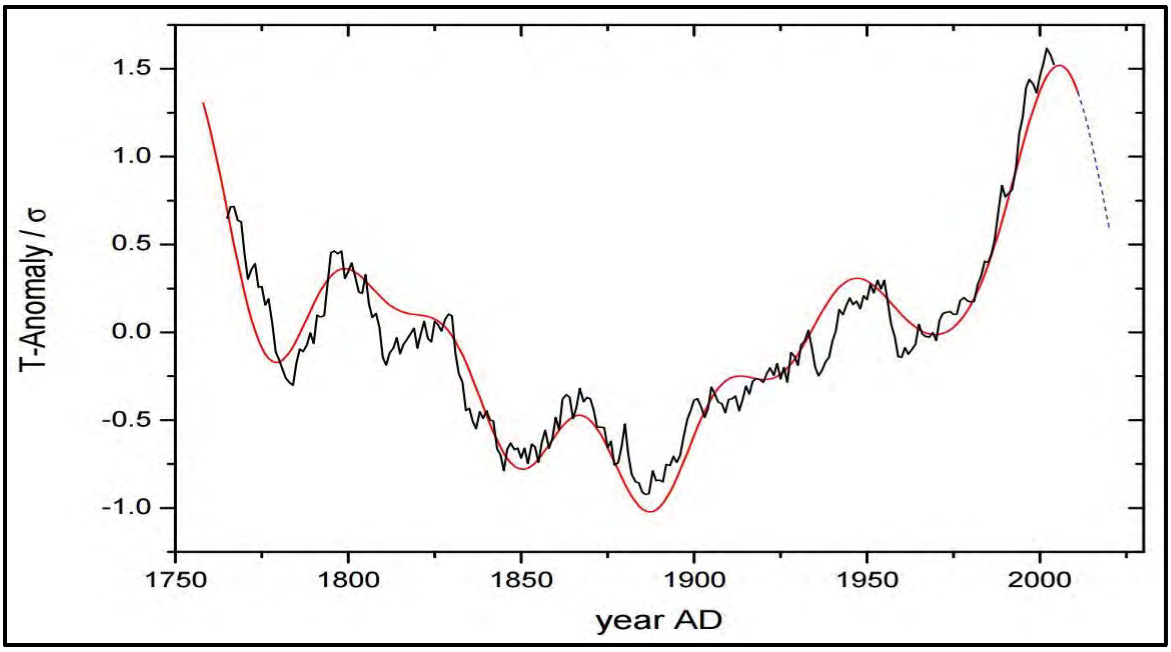


Figure 3.52 Cycle combination vs a city running average (H-J Lüdecke et al., 2013)

The data from these six European cities are revealing about the conditions in Europe in ~1750, a date which denotes the end of the so-called pre-industrial era. In effect, the temperature conditions then, appear to have been very similar to the present – which may go some way towards explaining the very small TSI change reported by the IPCC compared to the present.

3.5.3.5 Prediction of future global temperatures using known climate cycles

Prediction of future climate states is fraught with difficulties, as have been seen from the failure of the IPCC scenario's from FAR in 1990 to predict even 25 years ahead by driving a model just with CO_2 (Figure 3.54). But more predictive success should be had by utilising climate cycles. One climate researcher, who concentrates on solar and astronomical cycles - and is brave enough to project future climate states, is Nicola Scafetta.

Scafetta has found that a comparison between different periods of Sunspot cycles lends support to the idea that they are not simply random in activity, but form a part of a larger cycle – and repeating patterns which are discernible (Figure 3.53). In the spectrum of man-made climate change belief/non-belief, Scafetta falls into the category of what is termed a 'luke-warmer'; that is, someone who sees data supporting the idea, and that man's GHG emissions are causing some warming, but that the resulting warming is not dangerous and may be net beneficial.

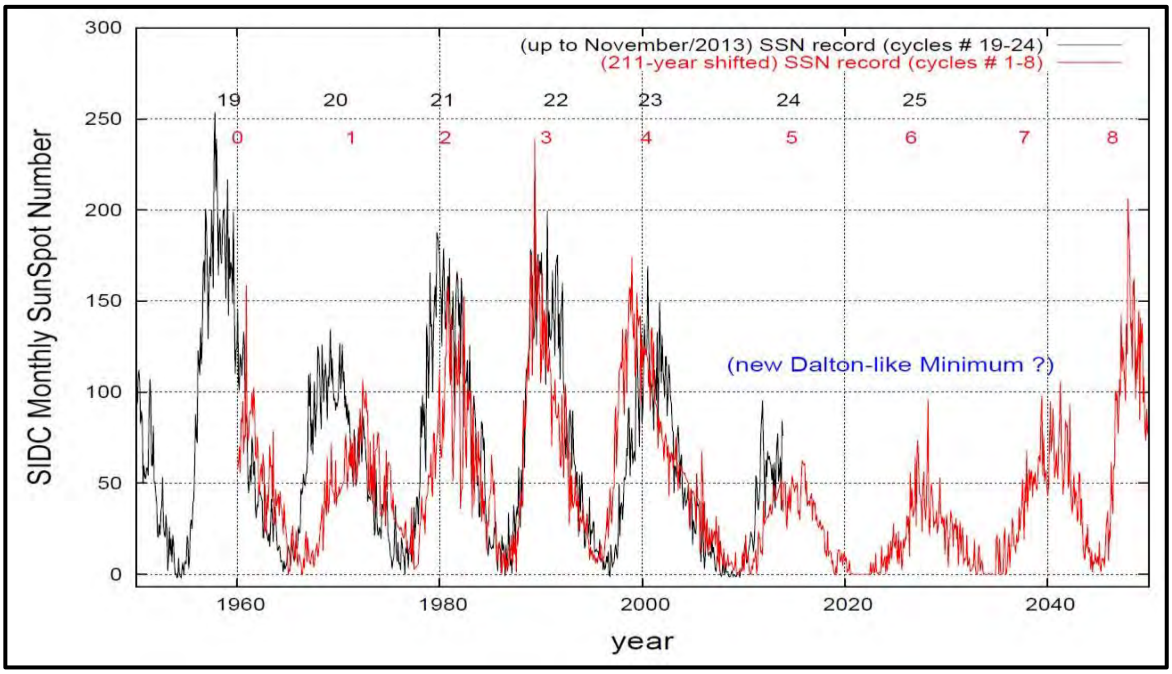


Figure 3.53 SC19-24 (black) superimposed onto SC0-8 (red) (Scafetta, 2014)

The above figure takes SC0-8 (solar cycles 0-8) (in red) and shifts them 211 years forward so that they are transposed onto the current period of Schwabe sunspot cycles. SC19-24 (in black), can be seen; SC24 is the current cycle, it is the weakest in over 100 years, and it is not projected to end until ~2022. The cycles can be compared directly, and as the illustration shows, there is a very good correlation between these sets of cycles, which confirms the existence of a ~211 year, solar cycle; this is the De-Vries/Suess climate cycle. SC5 marked the start of the Dalton minimum, which lasted from 1790-1830. SC5 peaked in ~1805, so if this is taken forward 211 years, then the peak of SC24 would be expected to be ~2016, as it was. This has led Scafetta and some other solar scientists to say that the climate system is now entering a new Dalton minimum cooling type period.

3.5.3.6 Will anthropogenic CO_2 save Earth from a new Dalton minimum?

What kind of climate can be expected? Historical records would be the guide here, think; shorter growing seasons, more wintery days, higher snowfalls, cooler conditions, and extreme weather. Historical events like Napoleon's armies freezing to death in Russia in 1812, and large volcanic eruptions such as Tambora in 1815 which caused the 'year without a summer' in 1816.

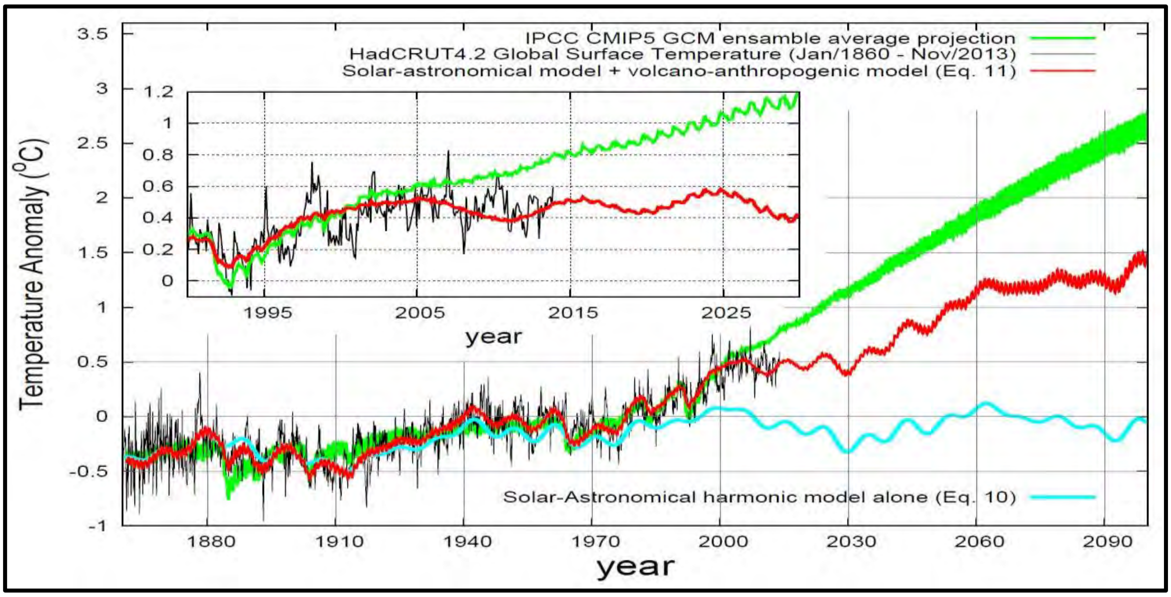


Figure 3.54 Actual trends (black) against Scafetta (red) and IPCC (green) (Scafetta, 2014)

Returning to Dalton minimum-like climatic conditions would not be pretty on a planet with a population of 7.5 billion to sustain. Even worse would be a descent into a Maunder minimum little-ice age type climate, which is also possible. Scafetta does not project this dire state of climate change, although other solar experts do (Abdussamatov, 2015). Instead, according to his projections, some anthropogenic warming appears to be taking place on top of what are the normal climatic cycles, (in blue, Figure 3.54). The IPCC climate model projections are seen in green, and Scafetta's cyclic projections, (with some added warming effect from humans) is seen in red. In Figure 3.54, IPCC model projections (or scenarios) in green, are incremental with CO_2 changes, and seem to be both too rapid and too monotonic to be realistic. The blue line projection consisting only of climate cycles is seen to be too low, but the more nuanced projection which includes both of these, accords well with real temperature development (seen in black). Scafetta's hind-casts also accord much better with past climate changes than the scenarios from any government-owned billion-dollar global circulation models.

3.5.4 More support for the null hypothesis

3.5.4.1 Atmospheric CO_2 changes lag ocean and air temperature changes

It has been known for some time from proxy records, such as those from the Vostok ice cores that atmospheric CO_2 concentrations track along *after* changes in temperatures, (Petit et al., 1999) with the gap generally being between 200 and 800 years. This brings into question the idea that CO_2 is driving global temperature changes, as the climate models operated by EGGWH advocates predict. However, it has been disputed that this order of events is always the case (L. Khilyuk, 2003), even on longer time-scales (Shakun et al., 2012). Work has also been done on the causes of current atmospheric CO_2 changes, and it appears that warming initiates in the oceans, south of the equator (in blue) (Humlum, Stordahl, & Solheim, 2013), and then a peak in atmospheric CO_2 concentrations is seen 10 months later (in green, Figure 3.55).

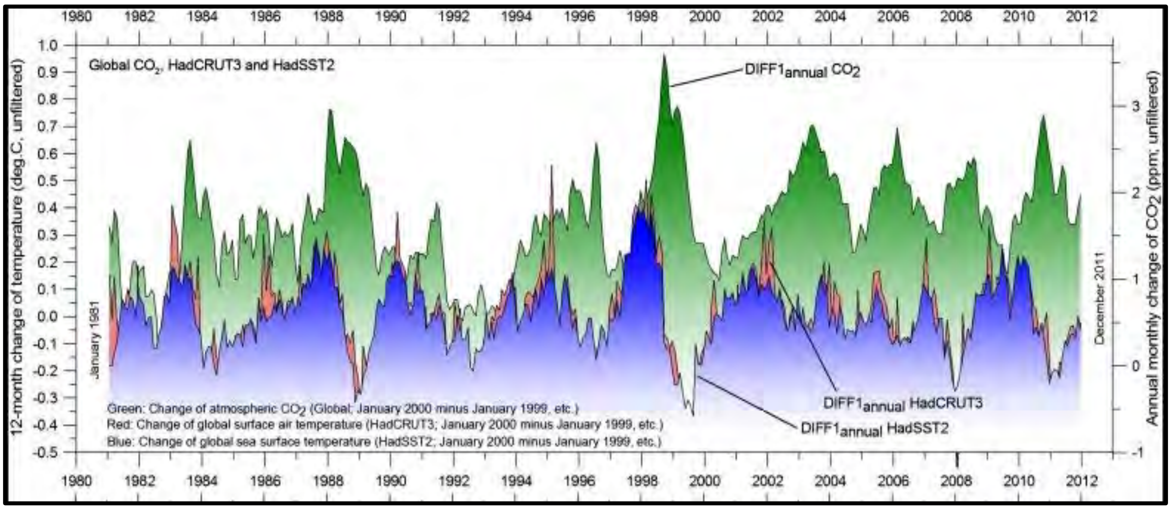


Figure 3.55 Ocean temperatures change first, then CO_2 changes (Humlum et al., 2013)

There does not appear to be a close causative relationship on short time-scales between anthropogenic CO_2 emissions and changes in atmospheric CO_2 concentrations (Figure 3.55) either (Figure 3.56). Here, Henry's law seems to prevail, where the atmospheric CO_2 changes are determined mainly by near-surface ocean temperatures (Weiss, 1974) (Humlum et al., 2013).

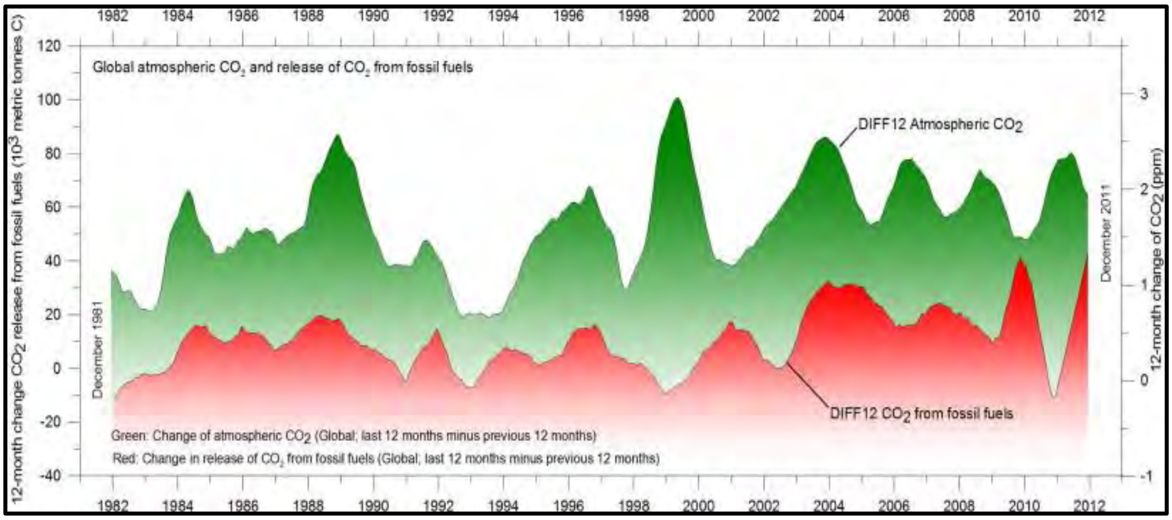


Figure 3.56 Atmospheric CO_2 changes vs human emissions (Humlum et al., 2013)

3.5.4.2 *Cloud cover is nature's negative feedback mechanism*

Clouds are powerful and integral to the climate system; playing a much greater role that allotted to them in climate models, they even balance the albedo between the hemispheres to within 0.2 W/m² (Stephens et al., 2015). Low clouds in the tropics and temperate zones provide cooling by reflecting short-wave solar insolation in the daytime and warming at night by reflecting OLR. High clouds generally provide warming by being too thin to prevent the entry of insolation, but being thick enough to reflect OLR radiation.

3.5.5 The Arctic and the Antarctic

Often, the Antarctic gets forgotten, the reason is that most climate science is done in the N.H. and because not much seems to be happening in the Antarctic. The action of clouds generally, is for high clouds to warm, and low clouds to cool. But one very interesting feature of clouds is that all clouds over both the Antarctic and over Greenland provide warming. This is because even though clouds are fairly white (albedo 0.3 to 0.8) (Charlson, Lovelock, Andreae, & Warren, 1987), they are not as white as those surfaces (Antarctic average albedo 0.8, fresh snow 0.9) (Wiscombe & Warren, 1980); this means that they are not as reflective as those surfaces, and so even if they are present in the daytime, they do not cool those surfaces more than the absence of the clouds would. This results in a warming effect for any clouds which are over those ice caps at any height and at any time. This difference is important, as will be discovered.

The EGGWH predicts that both of the polar regions should warm more than the tropical regions if the greenhouse effect is causing the warming (Polyakov et al., 2002) this is in all the models, the theory and in the logic of greenhouse warming, which should be global in extent because the GHG are well-mixed and extend globally. Yet instead, far from warming more than other regions, Antarctica has been cooling for decades, in fact since 1966 (Doran et al., 2002). Antarctica recently attained its greatest measured sea ice extents of 20 million square kilometres, in 2015 (UIUC, 2017). Both the land ice and the sea ice in the Antarctic have been gaining mass recently (Zwally et al., 2015). This Antarctic cooling has been called a 'mystery' by many proponents of GHG warming, and a lot of effort has gone into trying to explain it (Thompson et al., 2011) (Doran et al., 2002). However, the Arctic, as per the prediction of the climate models, and the theory of EGGWH, has been warming in recent decades. But this current warming is no greater in extent and length to one which is well documented, happened 1928-1945, and shows up in the HadCRUT4 Arctic data, (Figure 3.57).

3.5.5.1 The canary in the coal mine; Antarctica cools as the globe warms

Predictions by the hypothesis of the EGGWH – and all the projections from its models show that both poles must warm together and must undergo the most warming of anywhere on the planet – if the cause of the warming is the GHE (Lacis, 2010). This is because atmospheric CO_2 absorbs infra-red emissions from cold places more, due to them being in the 12-16 micron band; warmer places emit at shorter wavelengths around 10 microns, which is in the so-called 'atmospheric window' (Mathar, 2004). Yet the exact opposite is occurring; the Arctic and the Antarctic generally move in thermally opposite directions, when one warms the other cools and vice versa in a 'see-saw' (Ingólfsson, Hjort, & Humlum, 2003) (Figure 3.57), and this has continued through the current period of global warming. Moreover, these changes appear to be more related to known climate cycles and TSI changes than to any effects from GHG. For example, the Arctic has been warming since 1979, but a very similar warming in rapidity and size, also occurred 1910-1944 according to the UK's Hadley centre and the climate research unit's Arctic temperature graph (Figure 3.56). This graph shows the 70-90N monthly surface air temperature anomalies from HadCRUT4 compared to the base period 1961-1990 (CRU, 2016). The poles appear to be involved in a temperature see-saw (Chylek, Folland, Lesins, & Dubey, 2010) with one pole warming while the other cools and vice versa, with the fulcrum being at 60° south on a ~60-year cycle (Velasco et al., 2008) – this does not fit at all well with the GHG warming hypothesis (Figure 3.35). The recent 'see-saw' of the poles going in opposite directions is a mystery when the EGGWH is taken to be correct; yet the bi-polar see-saw is a long-term and a persistent feature of the climate system (Bilt, 2016). But when looked at through the lens of cosmoclimatology, the see-saw makes perfect sense, and has to do with the nature and actions of clouds; it fits perfectly with the predictions of the cosmoclimatology hypothesis.

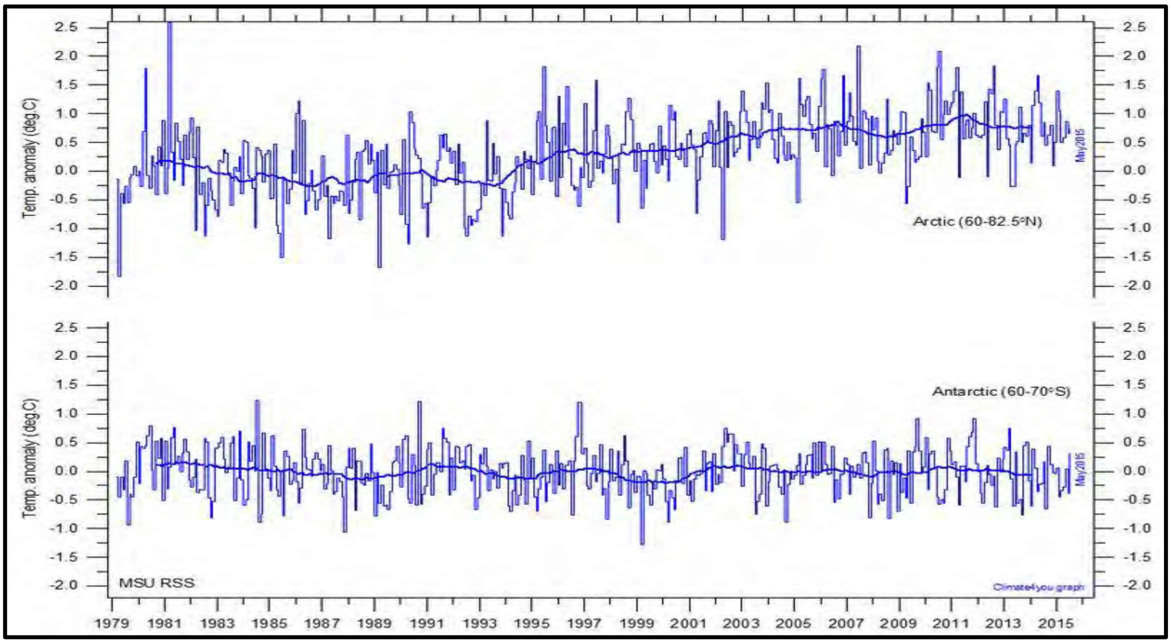


Figure 3.57 The polar see-saw (Climate4you MSU RSS)

3.5.5.2 TSI climate forcing in the Arctic and black carbon pollution

This Arctic cycle of warming (Figure 3.58) appears to be driven by the well-known and well documented 61-year Yoshimura climate cycle which permeates many climate changes, including the AMO, the PDO, the NAO and the SOI, (Velasco & Mendoza, 2008; Yoshimura, 1979). This cycle (along with the Schwabe, Hale and Gleissberg climate cycles) are related to the Sun/planets and all these cycles manifest from solar activity changes, solar barycentre cycles or other planetary-induced solar changes. The equator to Arctic pole temperature gradient appears to be closely related to TSI changes (in red, Figure 3.59), there being a strong decadal correlation (Soon & Legates, 2013).

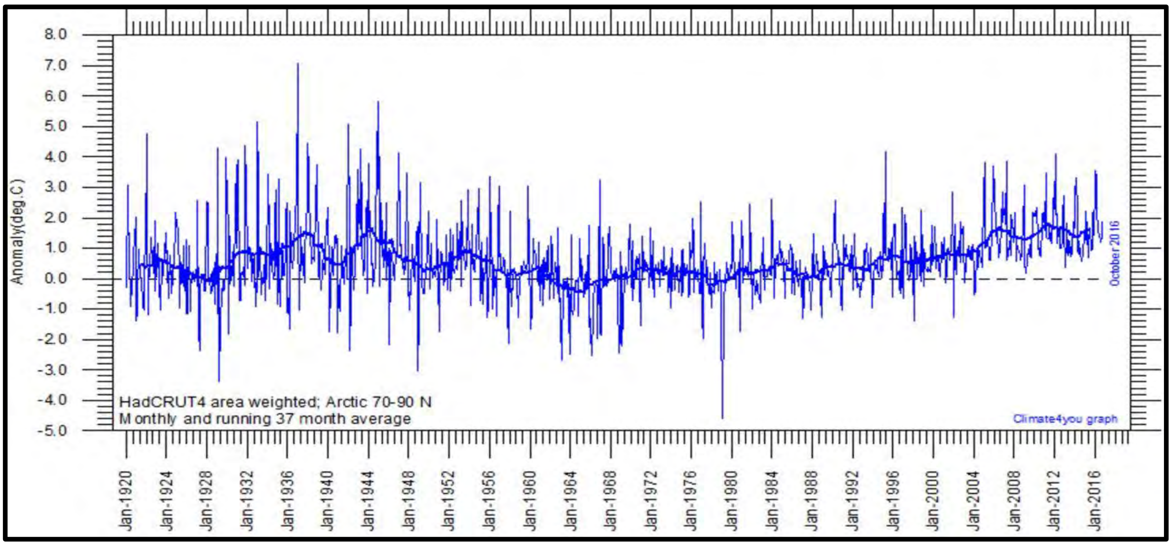


Figure 3.58 HadCRUT4 Arctic temperatures 70-90N 1920-2016 (Climate4youArctic)

This is more evidence that the recent Arctic temperature rise is not just related to increasing atmospheric GHG concentrations, and means that climate dynamics may need to be revised for previous warm periods such as the Eocene and the late Cretaceous.

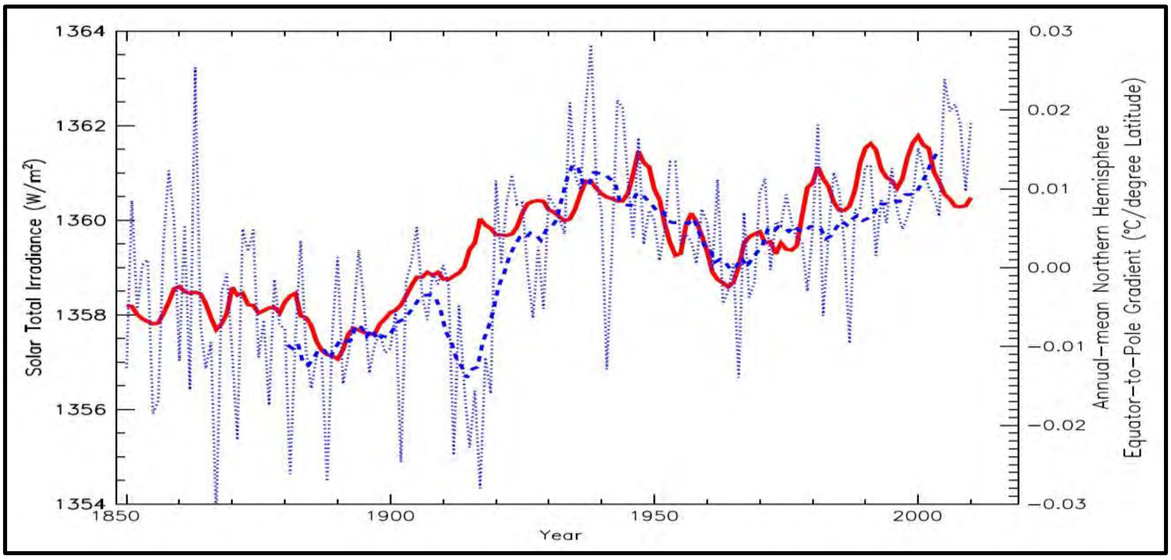


Figure 3.59 NH equator-to-pole temp gradient (blue) vs TSI (red) (Soon & Legates, 2013)

Arctic sea ice melt; if the Arctic sea ice is melting more currently than it did in the last cyclic Arctic warming in the 1930's (although there is no evidence that it is), it may not be related to temperature, since both periods were equally warm. Instead it could be albedo-related, i.e. caused by the presence of pollutants such as black carbon (M. M. Holland, Bitz, & Tremblay, 2006). There is no doubt that more of this pollutant has been seen over recent decades, with higher rates of bio-mass burning globally, and the rapid industrialisation of China (R. Wang et al., 2012), which has seen the construction of many hundreds of old-generation and highly polluting coal-fired power stations.

3.5.6 Solar physics and climate change on the planets

3.5.6.1 The infra-red iris; is this another negative feedback mechanism?

Lindzen's adaptive infra-red iris effect (Lindzen et al., 2001) highlights a weak point in climate models, namely their treatment of clouds. The results of this empirical study, using a Japanese satellite to monitor cloud changes in the tropics are that "..cumulus coverage decreases about 22% per degree Celsius" of surface temperature rise. This represents a very strong negative cloud feedback mechanism, which according to the authors operates between -1.1 and -0.4 (the term *fc* for cloud feedbacks in equation 4), which in itself is strong enough to completely eliminate the +0.4 (Schneider et al., 1999) or the +0.15 (Dessler & Sherwood, 2000) shown in cloud feedbacks for initial CO_2 warming by previous research. Although further modelling work on stratospheric water vapour feedbacks, finds that it is positive (Dessler, Schoeberl, Wang, Davis, & Rosenlof, 2013) and this effect could be significant if the value assigned to it of +0.3 W/m².K is correct. The extent of cloud cover varies directly in a negative feedback mechanism to several parameters, including top of atmosphere TSI and hemispheric temperature differentials. Empirical support for Lindzen's adaptive infra-red iris effect, or OLR feedback can be seen in a comparison between OLR and HadCRUT3 temperature anomaly (Figure 3.60).

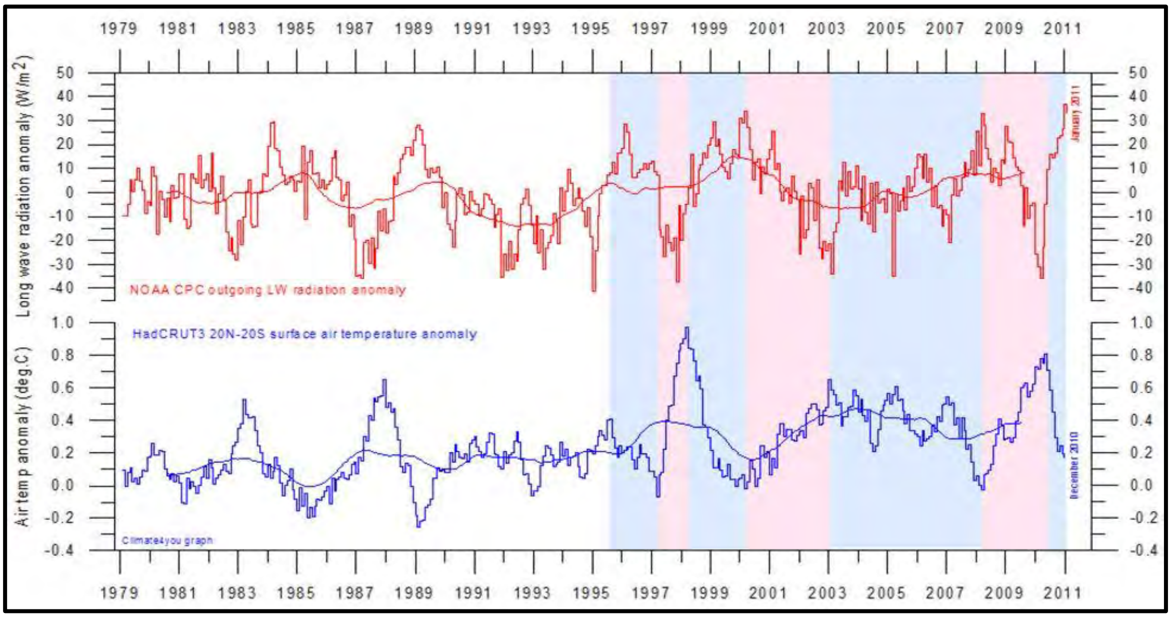


Figure 3.60 OLR responds to changes in surface temperature (Climate4you OLR)

Blue shading indicates a cooling surface and red shading indicates a warming surface; the OLR appears to respond exactly as stated by Lindzen, Chou and Hou by allowing radiation to escape when the surface warms and preventing its escape when it cools. The effect is not small; a change in OLR of 75 W/m² occurred between January 2010 and January 2011 (Figure 3.60).

3.5.6.2 Is the climatic effect equivalent for insolation and back-radiation?

The generally accepted radiative forcing from a doubling of atmospheric CO_2 is 3.7 W/m² (Team et al., 2014). But is there an equivalence between increased solar insolation and increased back-radiation from atmospheric GHG as far as heating the surface and the lower troposphere? In other words, does an extra 3.7 W/m² of back-radiative forcing from GHG have the same climatic effect as an extra 3.7 W/m² of short-wave insolation arriving at the surface? The EGGWH partly depends on this being accurate. In the AR4, it was shown that the relative efficacy for GHG is 1.1 and for solar 0.8 (Solomon, 2007) making the relationship 1.375x in favour of GHG; the difference being principally due to the differences in distribution, both geographically and vertically. This would mean that a GHG forcing of 3.7 W/m² is equivalent of a solar forcing of 5.1 W/m² and so the GHG forcing would be stronger per watt in its climatic effect.

However, other scientists find the opposite, i.e. that a given solar forcing has more effect than the same forcing from GHG (Irvine, 2014). If it can be shown that GHG are less effective than solar for the same forcing, then this would also mean a reduction in the time for a TOA equilibration to take place – effectively lowering the climate sensitivity (Forster & Taylor, 2006).

3.5.6.3 Can back-radiation from GHG heat the oceans?

The Earth's surface is mostly water, around 70% in fact, and the back-radiation from CO_2 is mostly centred on 15µm, (LW on the graph, Figure 6.61) but water is almost opaque at this frequency; a penetration of only around ~5µm is possible, with 99% of the radiation absorbed before penetrating 15µm (Irvine, 2014). It's extremely unlikely that back-radiation from atmospheric CO_2 could possibly heat the oceans significantly with this depth of penetration; in fact, cooling by evaporation seems to be much more likely.

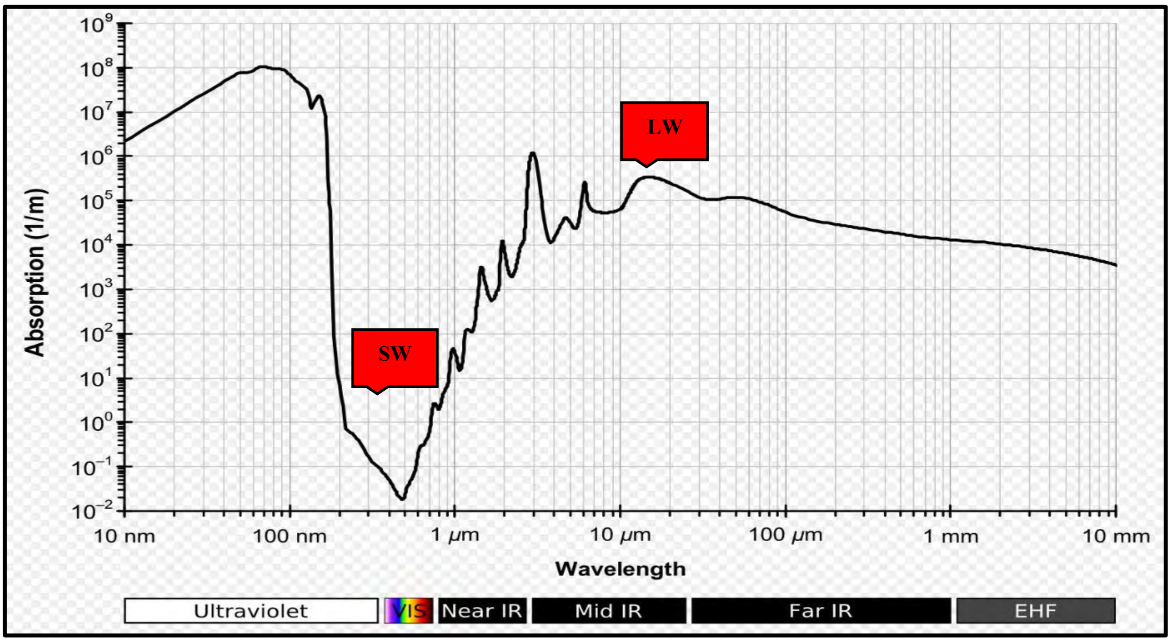


Figure 3.61 Absorption spectrum of water (Kebes at English Wikipedia, 2017)

Yet the literature cited in IPCC reports always refers to the increased ocean heat content (Levitus et al., 2009) as being evidence for man-made climate change via the greenhouse effect of CO_2. But, it is at direct solar insolation wavelengths (SW on the graph), that water can be penetrated - and heated – to a depth of hundreds of metres (Figure 3.61).

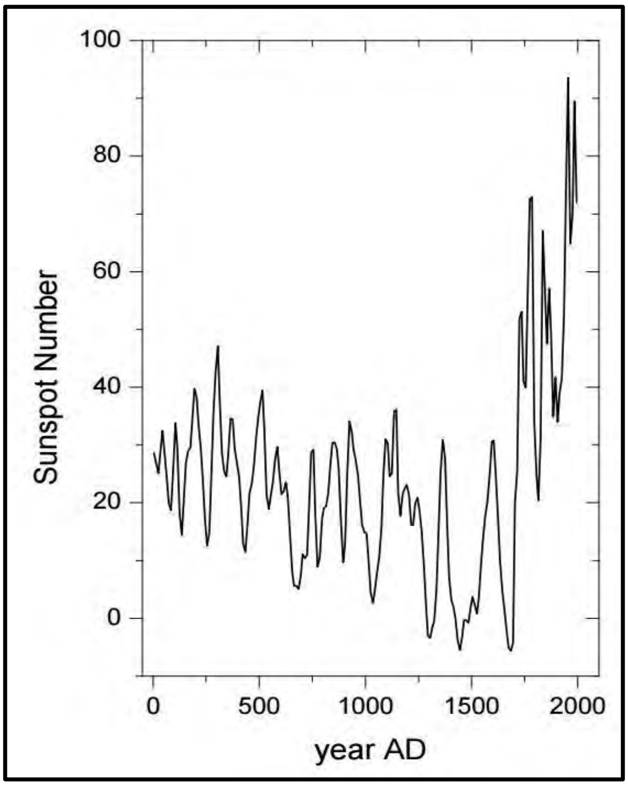


Figure 3.62 Reconstructed Sunspot number last 2ky (Horst-Joachim Lüdecke, 2011)

It therefore seems more logical that the main reason for a warming ocean is an increase in direct solar insolation; note that this need not be the result of an increase in TSI, it can happen through a reduction in cloud cover. However, solar activity has increased dramatically during the last two centuries, and in particular, has hit very high levels during the second half of the 20th century (Figure 3.62).

3.5.6.4 Highest solar activity for 8ky

The sudden and rapid rise in solar activity is demonstrated by the sunspot number (SN) record (Horst-Joachim Lüdecke, 2011) over the last 2ky (Figure 3.62).

An article in *Nature* found that;

"..the level of solar activity during the last 70 years is exceptional, and the previous level of equally high activity occurred more than 8kya…and almost all of the earlier high-activity periods were shorter than the present episode" (Solanki et al., 2004).

See Figure 3.63, where the red line is the measured 10-year averaged Sunspot number (SN) since 1610, the blue line is SN reconstructed from ^{14}C, the green line is the local reconstruction of SN from ^{10}Be, and the dashed magenta line is the global reconstruction of SN from ^{10}Be.

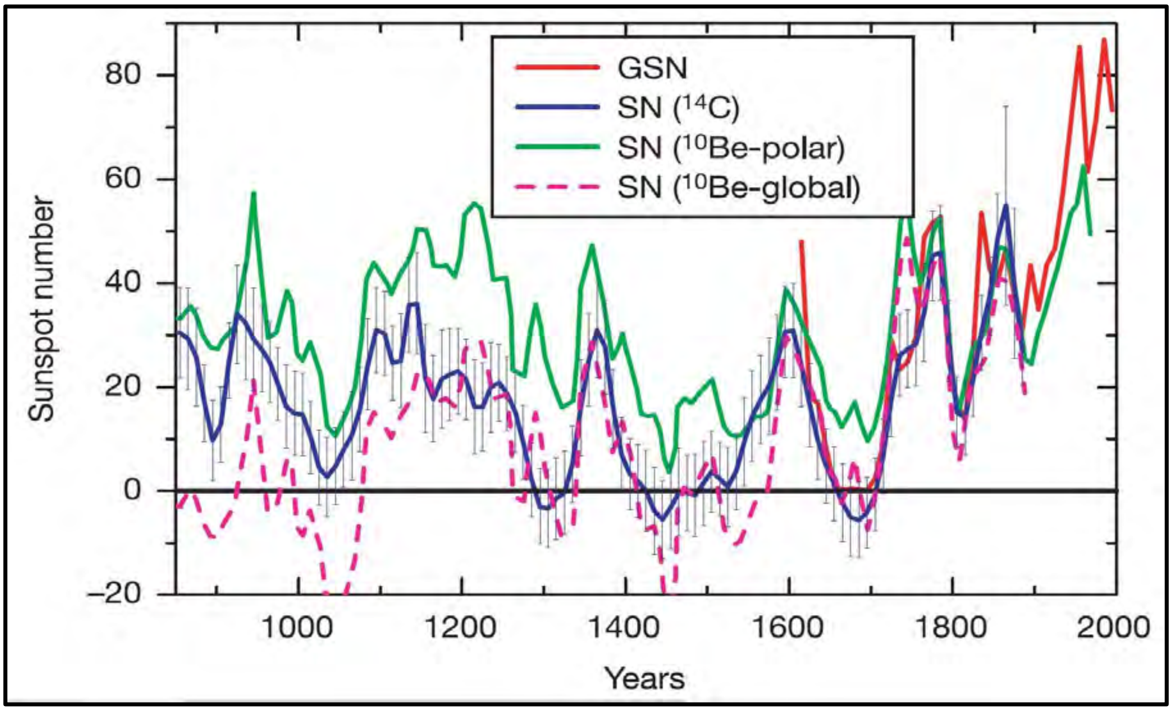


Figure 3.63 Multiple Sunspot number proxies since 1610 (Solanki et al., 2004)

Other researchers also find that the level of solar activity in the latter half of the 20th century has been the highest for thousands of years (Usoskin, Solanki, & Kovaltsov, 2007). Some show data which says the current level is in fact the highest for 11,000 years (Figure 3.66) (Solanki et al., 2004).

3.5.6.5 Climate change on planetary bodies

Planetary bodies which have atmospheres thick enough for their lower levels to be dominated by auto-compression/convection and not radiation are Venus, Earth, Jupiter, Saturn, Titan, Uranus and Neptune. Despite their widely differing temperatures, atmospheric compositions and top of atmosphere flux of solar irradiance, they all display a very similar temperature gradient signature in the regions of their atmospheres which are >0.1 bar (Figure 3.35). Additionally, for any planet one would expect that energy in = energy out and this is what the S-B calculation of planetary temperatures relies on, yet for the Jovian planets, this energy relationship does not operate; in fact, all of them emit a lot more energy than they receive (Hubbard, 1984).

Neptune is the most extreme in that the planet emits 2.6 (Pearl & Conrath, 1991) times the energy that it receives from the Sun. Neptune is the outermost planet and obviously receives the least solar energy of any planet. Contrary to what might be expected its atmosphere is very active with the strongest wind speeds in the Solar System at 580 m/s and a measured temperature of 750 K (Broadfoot et al., 1989) in its thermosphere. Oddly, Neptune's 'surface' temperature is virtually the same as Uranus even though the planet receives only 40% the Sunlight that Uranus does. At a pressure of 1 bar, the temperature on Neptune is 72 Kelvin (Table 3.5). All of this energy must come from an internal energy source which remains 'unknown' but some speculate it is heat left over from the formation of the planets (Williams, 2004), but if adiabatic auto-compression and the thermal gradient it forms is considered, the measured temperatures and the high observed atmospheric energy content may start to make much more sense.

3.5.6.6 Is the brightening of Neptune related to solar activity?

"From 1972 to 1980 Neptune's reflectivity appeared to correlate well with solar UV variations during the 11-year solar cycle (G. Lockwood & Thompson, 2002). But from 1980 to 2000, Neptune brightened continuously, by 11% at 472 nm, with most of the increase coming after 1990 (Sromovsky, Fry, Limaye, & Baines, 2003)."

Figure 3.64 is photometry of Neptune 1920-2000 (G. Lockwood & Thompson, 2002) and can be compared to the Earth's temperature anomaly, solar TSI and the solar UV flux over a similar period in Figure 3.65. Note that one of the main arguments of EGGWH proponents has been that TSI declined after 1960 and so could not have been responsible for the global warming seen post-1960. The post - 1960 'fall' in TSI is programmed into all CMIP-5 global circulation models (Allen et al., 2014) and is used for attribution in the models, and in the relative radiative forcing's of the AR5 synthesis report (Figure 3.6). Firstly, solar activity involves more than just TSI changes; and also note that the TSI 'peak occurring in 1960' is strongly disputed in the literature (Scafetta & Willson, 2014).

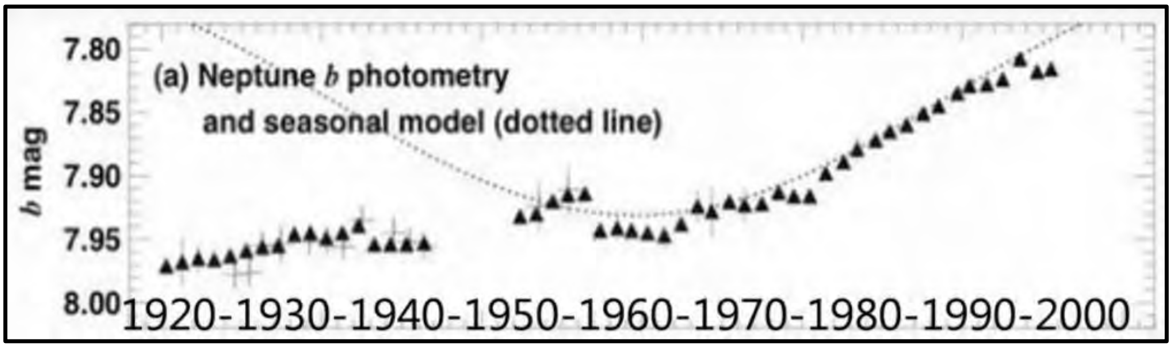


Figure 3.64 Neptune magnitude 1920-2000 (G. Lockwood & Thompson, 2002)

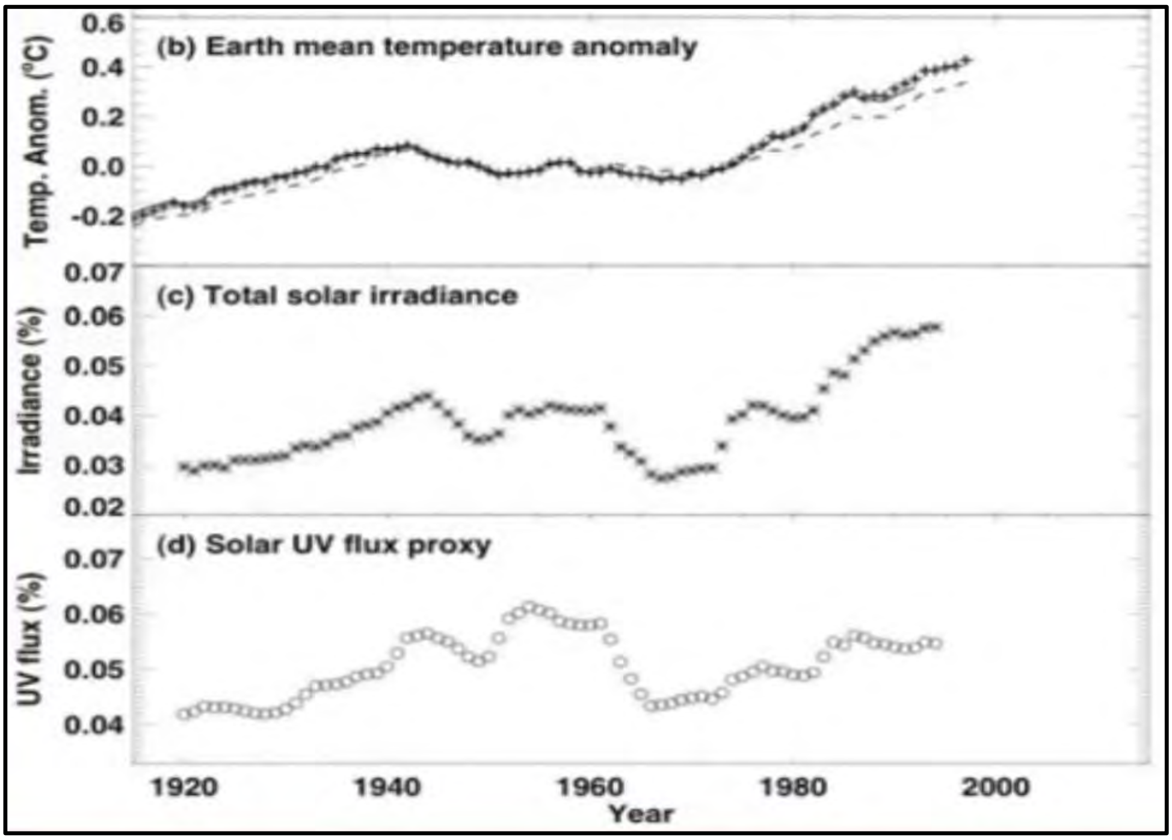


Figure 3.65 Neptune brightness, Earth temperatures (G. Lockwood & Thompson, 2002)

3.5.6.7 Changes in Pluto's atmosphere and brightness

Astronomers also found 'considerable changes' in the atmosphere of Pluto in a 2002 occultation (Pasachoff et al., 2005) (Buie et al., 2002) with the atmosphere doubling in height and the surface atmospheric pressure also doubling at all heights since measurements were last made in 1988. Further observations in 2006 showed little change since 2002, but referred again to the 'remarkable changes' which took place in the 1988-2002 period (Elliot et al., 2007). This is indicative that the actual effective peak in solar activity probably occurred around 2000, and not in 1960.

"Pluto's atmosphere below 1,230km cannot be described by current physical models and showed remarkable structural changes during the 14 years 1988-2002" (Buie et al., 2002).

Note that Pluto's perihelion was in 1989, so for almost the entire 1988 – 2002 period Pluto was moving away from the Sun, therefore the large energy increase observed in the atmosphere presumably could not be due to Pluto moving closer to the Sun. During these dates, Pluto and Neptune were quite far apart, and so the likelihood of changes on both planets being caused by a directional increase in solar energy such as a CME is unlikely.

3.5.6.8 Changes on Mars

Mars has also seen recent climate change with the accelerated melting of the southern polar ice cap in the years 1998-2006 (Fenton, Geissler, & Haberle, 2006). There is also considerable evidence that Mars once had an active hydrological cycle, perhaps ~3Gya (Montmessin, 2006); for this to happen, Mars must have had a thick enough atmosphere to keep at least the equatorial regions of the planet above the freezing point of water. This could have been as much as several bars of pressure (Pollack, Kasting, Richardson, & Poliakoff, 1987). Whether this warming on Mars was caused by auto-compression, GHG, or a combination of both is yet to be shown. Note that this could have been long enough ago to have been affected by the faint young Sun period (Hart, 1979) and so this would make it doubly difficult to explain the Martian warmth using only GHG.

3.5.6.9 Is there global warming on the planets?

As already noted, the second half of the 20th century had the highest solar activity in at least 4ky (Usoskin et al., 2007) (Yndestad & Solheim, 2017). The reason for the current grand solar maximum appears to be that several decadal and century – scale climate cycles peaked together around the year 2000 (Sharp, 2010) (Figure 3.54, 3.68 and 3.71). These cycles include; the Bond/Eddy, the De-Vries / Suess, the Landscheidt and the Yoshimura (Table 3.4). And as noted previously, a high level of solar activity happens every ~1ky (G. C. Bond et al., 1999). The excellent work by Bond et al with sediment cores from the North Atlantic, revealed this regular climate cycle by measuring deposits on the sea floor from ice drift, the so-called ice-rafted debris.

This cycle is also found in solar activity proxies such as $^{1°}$Be and ^{14}C in the GISP2 ice core record from Greenland (Stuiver & Grootes, 2000) and in temperature proxies such as ^{18}O. This solar activity cycle is very strongly correlated with climate changes (He et al., 2013). The Minoan warm period, the RWP, the MWP and the CWP, are the four recent climatic peaks that are correlated with the Bond cycle.

3.5.6.10 Neptune and the Schwabe solar cycles

Neptune's brightness varied with the Schwabe solar cycle (G. Lockwood & Thompson, 1991) until 1990, (so demonstrating that it does react to solar activity), when it started to brighten more than usual (Sromovsky et al., 2003) (Figures 3.64 and 3.65). Overall, Neptune has brightened considerably since 1920 when it was at a magnitude of

7.97, by 2000 it had reached a magnitude of 7.82, and is presently ~7.8. Neptune passed aphelion in 1947 and is slowly approaching perihelion, its closest approach to the Sun in 2030; does orbital distance from the Sun explain all of the recent brightening observed on Neptune? This seems unlikely given the very slight eccentricity of the orbit of Neptune, and the correlation which the brightening has with the Earth's 20th century climate changes.

3.5.6.11 Pluto and Mars

Pluto has also recently undergone 'considerable changes' (Pasachoff et al., 2005); the atmospheric pressure and height doubling (Elliot et al., 2007), even though the planet has been moving away from the Sun since 1989 (Buie et al., 2002). The accelerated melting of the southern polar ice cap 1998-2006 on Mars also lends credence to these postulates (Fenton et al., 2006), data from NASA's Mars Global Surveyor and Odyssey missions revealed that the carbon dioxide 'ice-caps' on Mars have been consistently diminishing. Because these ice-caps are frozen CO_2, and relatively thin being only a metre or so deep, they are more likely to react faster in terms of area reduction than Earth's land-based ice caps which are kilometres deep. According to British scientist Kate Ravilious;

"Martian warming hints at a solar, not a human cause for warming (Ravilious, 2007)."

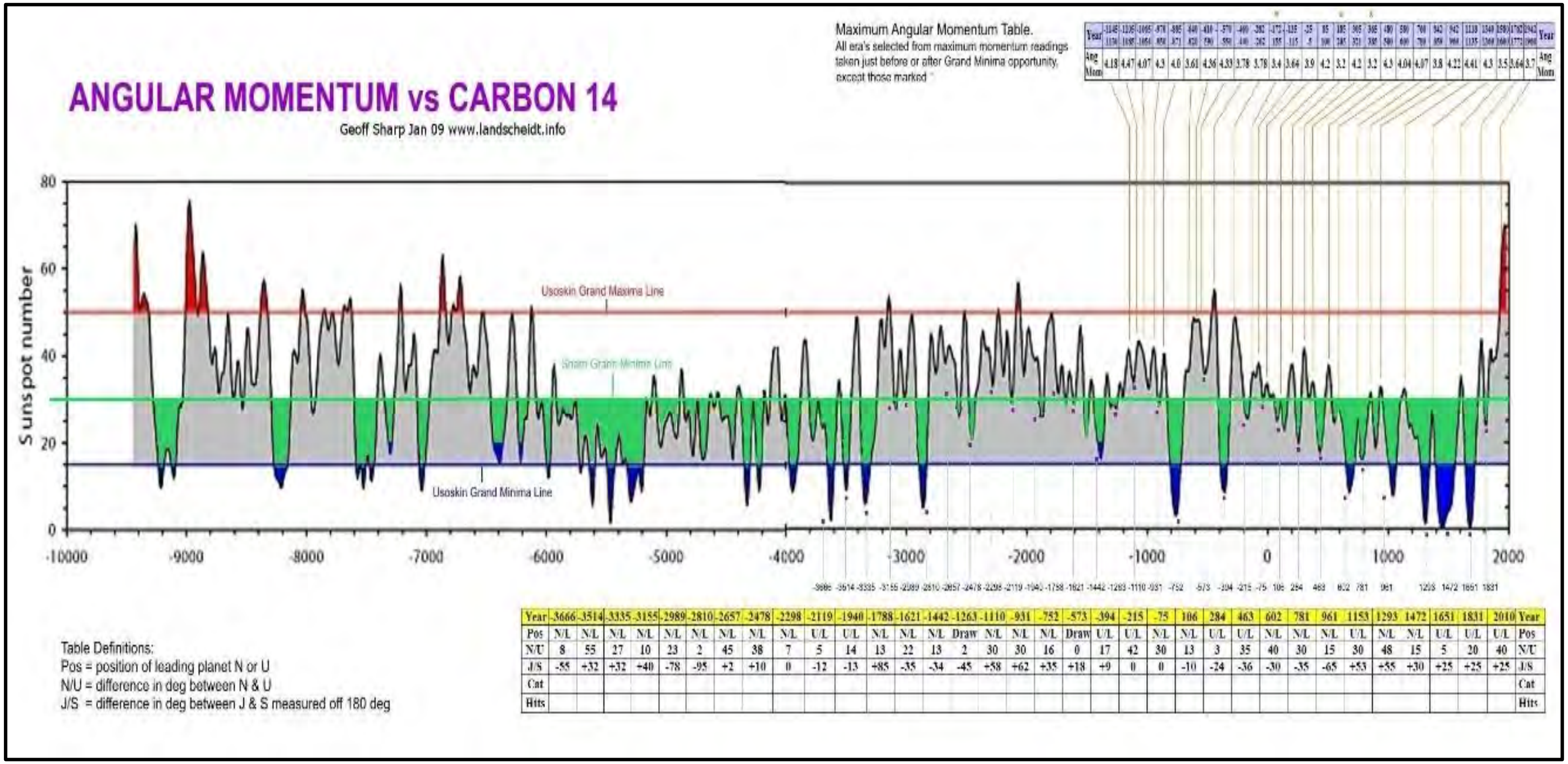


Figure 3.66 Grand Maximums in ^{14}C (Solanki, Usoskin, Kromer, Schüssler, & Beer, 2004)

3.5.6.12 Is a Solar grand minimum imminent?

Russian astrophysicist Habibullo Abdussamatov (Abdussamatov, 2015) uses long-term TSI change arguments to support his date of 2043 for the start of a solar grand minimum similar to the one last seen around 1700. Historically, grand minimums are common (Usoskin et al., 2007). He predicts a fall from the present TSI of 1,366 to 1,360 by 2040 (Figure 3.67), and a consequent fall in global temperatures (from current levels) of 1.2°C ±0.2°C by 2100. If correct, this scenario would return the climate system to LIA conditions, and would be disastrous for an Earth with its present large population of 7.5 billion. The fact is that many crops are now grown at high latitudes, both in Eurasia and in North America, and in colder conditions, many of these would fail.

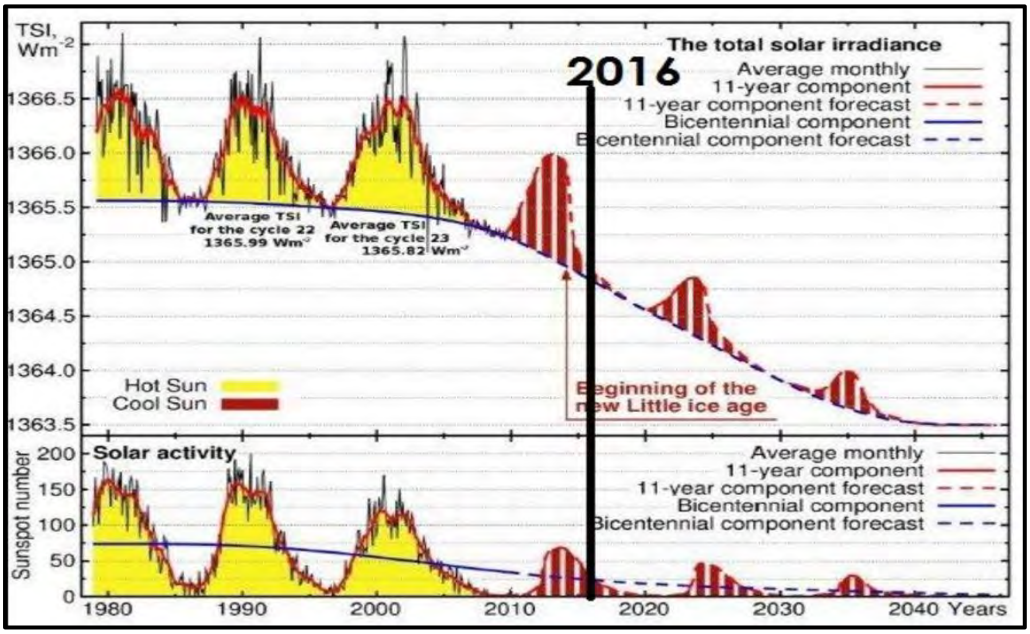


Figure 3.67 Projected TSI to 2040 (Abdussamatov, 2015)

The impact on humanity would be far worse than a similar rise in global temperatures. Needless to say, if this scenario develops, humanity will be totally un-prepared, since present actions are to get ready for higher temperatures and higher sea levels not colder temperatures and lower sea levels. Like many others who do not agree with the IPCC's reports, Abdussamatov has been derided as a 'denier' by climate activists, sections of the media, some politicians and even several 'mainstream' scientists. However, like Scafetta, Abdussamatov was correct in his prediction about the strength of SC24, and has some support from other solar astronomers, such as Svalgaard, who back in 2005 correctly predicted the current low peak of SC24, saying it will be the;

"..smallest in over a century" (Svalgaard, Cliver, & Kamide, 2005)

Archibald's prediction about SC24 was also correct (Archibald, 2016). Whereas mainstream groups, including the group at NASA were predicting a big cycle, and that it;

"..looks like it's going to be one of the most intense cycles since record-keeping began almost 400 years ago" (Hathaway & Wilson, 2006).

Pesnell published a compilation of 50 predictions of the cycle 24 peak (Pesnell, 2008), however, the actual peak was in fact, below any of them at 81.8 and the closest to this figure were (independently) Svalgaard and Archibald. Prominent solar scientist, NASA's David Hathaway, has now switched, and now says that the next solar cycle (SS25) will be the weakest in 200 years and that;

"....we are in a new age of solar physics" (New Scientist, 2013).

Unlike the IPCC, Hathaway has now realised that solar cycles other than the Schwabe are important, and is now investigating the Gleissberg, discovered by Wolfgang Gleissberg in 1933. Some independent researchers, for example Archibald, have noted the close similarity between consecutive solar cycle peaks of centuries ago, and those of today. This speaks about the reality of the existence of longer solar cycles like those already discussed. This repetitive nature of solar activity increases confidence about climate prediction, because as has been seen, there is ample evidence in support of the notion that solar activity and astronomical cycle are related to climate changes on Earth – even if the mechanisms themselves are not always known.

Researchers who closely follow these cycles say that at least another Dalton minimum-type of cooling is on the way; and possibly even a Maunder minimum type cold period, where the Sun went to 'sleep' for 50 years, and the Earth plummeted into what has been called the 'little ice age'. Archibald believes that a Dalton-minimum type cooling is coming, based on solar cycle 24 and 25 activity and length predictions (D. C. Archibald, 2009). Solar cycle length and global temperature changes have also been linked in other work (Lassen & Friis-Christensen, 1995). During the Maunder minimum, the ostensibly ~11-year Schwabe solar cycles became much longer, lengthening up to 22 years; this lengthening seems to be a feature of periods like the one centred on 1690 when the Sun had very low activity and no visible Sunspots for decades. Since that time, we have been lifted by the Bray (or Hallstatt) and the Bond (or Eddy) cycles; these longer-term cycles seem to underpin temperatures and prevent a severe cold period occurring (Euan Mearns, 2017).

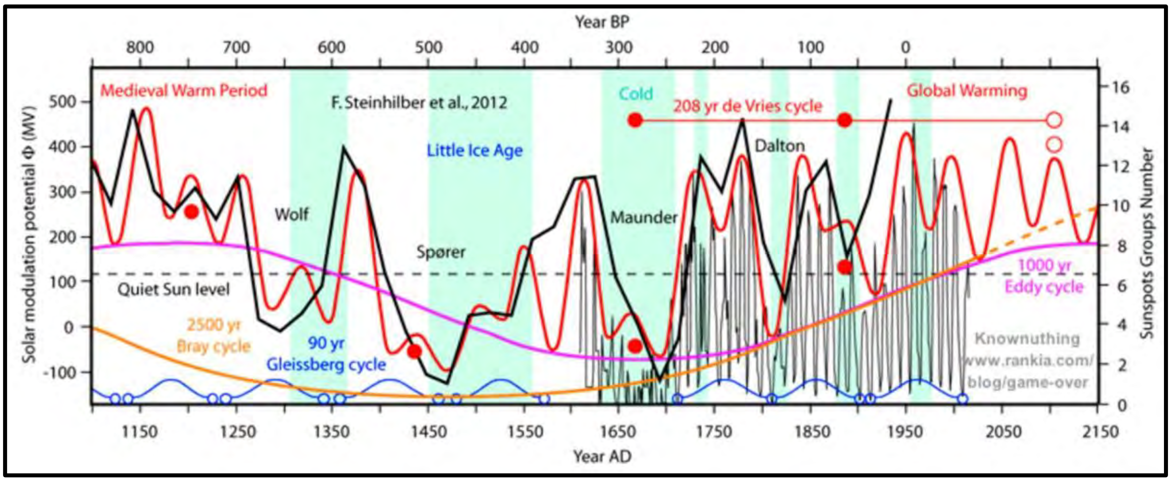


Figure 3.68 A compilation of periodicities in the last 1ky (Euan Mearns, 2017)

Hindcasting using CO_2 - driven global circulation models has been used (Rind et al., 2004) to infer that it was in fact the lack of man-made GHG that was mostly to blame for the Maunder minimum conditions, rather than the actual cause which was the same as for all the other cooling's and warming's that have been experienced all through the Holocene; natural variability (H. Zhang et al., 2015).

3.5.6.13 Putting periodicities together with climate change – last 1ky

A compilation of many of the periodicities which are known to be operating on the climate system during the last 1ky are represented in Figure 3.68. Longer-term cycles underlying climate are the 2.5ky Bray and the 1ky Eddy; both of these are close to a peak, the effect of which is to lift other, shorter cycles. Archibald thinks there is unlikely to be a very deep little ice age while these longer-term cycles are peaking.

Adjustment of the solar variability in red (Figure 3.68), to the Sunspots groups number (Svalgaard & Schatten, 2016) for the past 400 years and the solar activity is reconstructed by Steinhilber (Steinhilber et al., 2012). Shorter periodicities affecting the climate are the De-Vries (Raspopov et al., 2008), the Gleissberg (McCracken, Dreschhoff, Smart, & Shea, 2001) and the Yoshimura (Yoshimura, 1979). An important point is that of all the major cycles 60+ years in length, only the Gleissberg is presently at a low.

3.5.7 China's industrial revolution

3.5.7.1 Two thousand coal plants under construction or planned globally

China leads the way, with 400 coal-fired power plants now under construction, and another 800 planned, and is completing 2 per week (China coal, 2016), Japan is building

45 in the next 12 years (Japan coal, 2017), India is building hundreds and even Germany, the global leader in green energy, dozens. Overall, more than 2,000 large coal-fired power plants are either under construction or are planned globally.

3.5.7.2 China's massive emissions, are set to rise for decades to come

China has rapidly industrialised, and is now suddenly by far the world's biggest GHG emitter; while the per capita emissions of western countries such as the UK, USA and Australia have been declining since the early 1970's. More recently even the actual emissions totals of these countries have been declining - despite their rising populations, China's actual emissions have been massively soaring, especially since 2000. In the case of the USA, its actual emissions total has been declining since 2005, mainly because of the new resource of cheap natural gas, obtained through the new technology of sideways drilling and fracking. This has led to gas replacing coal for power generation in many places. The main reason for the fall in total U.S. CO_2 emissions over the last decade, has been because natural gas emits just 55% (Rochelle, 2009) of the CO_2 emissions of coal, for the same quantity of electricity generated.

China's emissions are now (2017) more than double that of the next biggest emitter, the USA; and are bigger than the USA, Germany, Russia, Canada, UK, Japan and Australia combined. Despite what is misleadingly being reported by green groups and the media, China is not reducing, and will not reduce its massive fossil fuel use for many decades. In fact, China will continue to expand its use of fossil fuels, in the form of coal, shale gas and oil, for many decades to come, at least until 2050 (Adams, 2015). What is true is that China aims to increase the *share* of renewables in its (then much larger) power mix; for example, to 20% by 2030. These will not be primarily wind and solar, since they have fallen out of favour in China due to their huge cost and production intermittency. In the main, the 'renewables' China speaks of expanding are hydro and nuclear. Wind and solar are the favourite renewables among the various green groups in the west, but together, they currently provide only 1.2% of China's power needs, and less than 0.5% of global energy needs.

Blessed with an enormous coal resource, China's rapid industrialisation since 2000 has caused a tripling in its use of coal, and the country now burns more coal than all the other 194 countries in the world combined. This consumption will not decline; China's 2020 energy plan includes a continued rise of 22% in fossil fuel usage (Adams, 2015).

Hundreds of old-style coal-fired power stations that China built to power its rapid industrialisation, were built too close to cities and have caused dangerous levels of air pollutants such as NO_2, SO_2 and particulates to exist there. China's solution to this problem is to build many new technology coal-fired power stations, but in the more remote parts of the country; and to renovate their old coal power stations. Currently, many of the old coal power stations are rapidly being converted to new high-efficiency low emissions technology (HELE) (Zhou, Yabar, Mizunoya, & Higano, 2016), the base of which is the use of ultra-supercritical (Weitzel, 2011) generation units. These are far superior in efficiency, and much lower in emissions than the operating coal plants in Australia. Typical of their newest plants, Waigaoqiao No3 near Shanghai, produces 38% more electricity than Yallorn in Victoria – with half the workforce and releases just one-seventh of the CO_2 emissions per MWh of generation (The Australian, 2017). Although CO_2 emissions are cut drastically with this new technology, for China, the real driving force behind this change has been to clean up city air of pollutants, not to cut CO_2 emissions. This new technology is the basis of the so-called 'clean coal' power revolution now sweeping across China and many other countries (Chen & Xu, 2010).

3.5.7.3 China's significant under-reporting of emissions

In 2015, it was discovered that China had been underestimating, or under-reporting its consumption (New York Times, 2015) of coal, by 600 million tonnes in 2012 alone. The error involved is equal to 70% of the entire U.S. coal consumption, and represents more CO_2 emissions than all of Germany, and increases global emissions by ~3%. China's emissions are now ~10Gt/yr. This is important, because it means that the take-up of natural sinks is even greater than previously thought, and means that CO_2 sinks are in fact increasing much more in line with the actual anthropogenic CO_2 emissions growth than previously thought. China's industrialisation has been so large and rapid that the rate of global anthropogenic CO_2 emissions virtually doubled overnight from 2002. Yet significantly, there was no incremental change to the regular atmospheric CO_2 increases. Professor Salby's work explains why (Salby, 2012) (University college, 2016).

3.5.7.4 World's biggest emitter blames the West for climate change

Although China is the globe's second-biggest economy (on some measures it is the largest), it is by far the biggest GHG emitter – its emissions being more than double that of the USA, nevertheless it blames the West for all the alleged man-made global warming.

Under the Paris agreement (Robbins, 2016a) China is considered to be a developing country, and as such not only do they have no binding emissions target, but under the charter are entitled to compensation for the supposed 'impacts' of manmade climate change through the 'green climate fund' to which only developed countries are expected to contribute. The contributions have commenced, and are slated to rise to 1% of GDP and to total US$100 billion per year by 2020. However, the biggest contributor to this fund (the USA) has now decided to pull out of the COP21 Paris climate agreement – leaving the future of the climate fund in doubt.

3.6 Is the science 'settled'?

3.6.1 Statements by learned societies

Claims have been made that the science in the field of climate is 'settled' (Keller, 2009). What is meant by this, when all scientists know that scientific questioning and inquiry in any of its fields never really ends? Scientific conclusions as presented in the peer-reviewed literature are always being questioned, and rightly so, because they are sometimes proven to be wrong. This is the scientific method at work, and this is one of the main ways that knowledge advances in any scientific field. Nevertheless, the American physical society (APS) has declared that;

"The evidence is incontrovertible: global warming is occurring" (APS, 2007)

Taken at face value, over a several century time-scale, this statement is banal and almost certain to be correct. But in context, they presumably mean that recent and man-made global warming is occurring; in effect they are supporting the IPCC's consensus statement not only without checking on its validity, but also leaving no room for debate. This declaration has led to the resignation of some of its members, including Nobel prize-winning physicist Ivar Giaever who stated in his letter of resignation that recently the global temperature has been;

"..amazingly stable...and human health and happiness has definitely improved" (Giaever, I; 2011).

Giaever has also made statements to the effect that physicists can dispute the mass of the proton, astronomers can dispute whether there was a big bang or not – so why can't scientists dispute whether man is causing dangerous global warming or not? His main issue with the APS statement is obviously with the inclusion of the word 'incontrovertible'.

The fact is that quite often in the past, the scientific ‘consensus’ of the day has been proven in subsequent work, to be completely wrong. Examples are by Galileo, Pasteur, Darwin and Einstein to name just a few. And sometimes, the scientific ‘consensus’ of the time has resulted in actions leading to horrible events and many deaths, for example when there was a scientific consensus on eugenics (R. Hansen & King, 2001). Some now believe that the danger to planet Earth from man-made climate change is so great that not only should the tried and tested scientific method be dispensed with, but reason and decency should be discarded as well. On the contrary, if the stakes are so high that is all the more reason to adhere strictly to the tried and tested scientific method, because then humanity shall proceed from a place of knowledge rather than from a place dominated by ignorance and fear.

The climate alarm has resulted in what is termed; ‘Post-normal science’ (Funtowicz & Ravetz, 2003), in which if the stakes are thought to be high, and decisions urgent, then uncertainties in the science are not a reason for delaying action. This type of thinking in the field of climate, has already led to actions (for example, the ethanol mandate) with the severe unintended consequences of starvation and death for hundreds of thousands, perhaps millions of the world’s poor (Goklany, 2009c) (Goklany, 2011) (Montford, 2015). Good progress was being made in reducing world hunger up until recently, but action on climate change has begun to reverse those gains with the percentage of undernourished rising from 16% in 2005 to 19% in 2009 (Goklany, 2009c). The serious consequences of the ethanol mandate has been described by Jean Ziegler of the UN to be;

“A crime against humanity” (Henning, 2015).

Recent papers have shown that there are in fact, no emissions savings from mandating ethanol (Liska et al., 2014). These costly mistakes both in terms of human lives and financially, reinforce the notion that the scientific method must be assiduously followed, and the empirical data valued rather than the prevailing majority opinion and projections of possible future climate states from models.

3.6.2 What postulates underpin the enhanced greenhouse effect?

The above statement by the APS and these ones by NASA;

“Scientific consensus: Earth’s climate is warming” and “Climate change is occurring” (NASA, climate change 2017)

These statements are uninteresting and even ordinary – if one is using the traditional meaning of these phrases. But the context of these statements infer that they are using the newer or a different meaning of these words, more in line with the IPCC or the UNFCCC meaning. This is made clear on the NASA site, by the inclusion of a letter sent to the U.S. Senate, which was signed by 18 leading U.S. scientific organisations (AAAS, 2009) which includes this statement;

"Observations throughout the world make it clear that climate change is occurring, and rigorous scientific research demonstrates that the GHG emitted by human activities are the primary driver…. there is strong evidence that ongoing climate change will have broad impacts on society, including the global economy and on the environment. The severity of climate change impacts is expected to increase substantially in the coming decades. (AAAS, 2009)"

These claims are based on the correctness of these five main postulates which underpin the EGGWH;

- that the relative climate forcing estimates (figure 3.6) of AR5 are correct
- that the initial warming ascribed to CO_2 is enhanced by water vapour feedbacks
- that the projections of the climate models can be correct
- that the projections of the climate models are correct
- that CO_2 is one of the main climate drivers, on all time-scales

These further postulates are contained in the IPCC reports and should also be noted;

- that all the increase in atmospheric CO_2 since 1750 has been caused by man
- that a warming climate will cause adverse climate changes
- that natural climate variability is now either small or non-existent
- that the current level of atmospheric CO_2 has not happened over a million years
- that the recent measured rise in atmospheric CO_2 is historically unusually swift
- that the temperature is now higher than it's been for thousands of years
- that the rise in global temperatures since 1750 are historically rapid
- that most of the rise in temperatures since 1950 are due to human emissions
- that the above postulate is >95% certain
- that adverse effects will occur over decades rather than much longer time periods
- that the climate research to date has been 'rigorous'
- that the scientific evidence for the above deleterious impacts is 'strong'
- that a man-caused sea level rise of 1m or more is possible by 2100
- that a man-caused rise in global temperatures of 4°C or more is possible by 2100
- that man can control future climate changes by reducing GHG emissions
- that man can reduce future sea level rises by reducing GHG emissions

- that man can control future global warming by reducing GHG emissions
- that using wind and solar power reduce GHG emissions
- that the climate is now so different to anything in the Holocene, that earth has left the Holocene and has started a new period, called the Anthropocene (Steffen, Grinevald, Crutzen, & McNeill, 2011)
- that replacing petrol with ethanol reduces human GHG emissions
- that wind and/or solar power can replace fossil fuel power sources
- that 'acting' on climate will help and not hurt the planet's poor

Needless to say, every one of these postulates in strongly disputed both in and out of the literature. What is not in dispute in the literature by scientists, is that the planet is on a century-scale global warming trend, which started from the depths of the LIA in ~1690 (Ljungqvist, 2010), and also that climate change is happening (in the *Dictionary.com* sense), as it always has before. Earth has always been either undergoing periods of global warming or global cooling; it really cannot stay at exactly the same temperature, because there are too many constantly-changing influences which affect global temperatures. Similarly, change is what climate does; the two words are a tautology; as long as the Sun is still shining, and the oceans currents moving, the climate cannot possibly stop changing.

3.6.3 Some problems with postulate 1.

Space is not available here for an individual debate on all of the postulates that are listed above, and are commonly associated with the EGGWH. However, some postulates will be examined in the light of the literature and the empirical data. Postulate 1 underpins the EGGWH; if the relative forcing's of man and nature are not close to those stated, the hypothesis must be invalidated. It is easily seen that if the relative radiative forcing's on the climate system are as detailed in Figure 3.6 in that human activity 1750 – 2011 totals 2.29 W/m² and natural forcing's total 0.05 W/m², then human activity perforce is *a factor of 45.8 times greater than the total impact of natural variability* over this specified time. This relationship when converted to percentage terms, leads directly to the following conclusions;

- <u>Human activity causes >97.9% of any current global warming / climate change</u>
- <u>Natural variability causes <2.1% of any current global warming / climate change</u>

Natural variability as defined by the relative forcing estimates in AR5, includes only the TSI change of 0.05 W/m² that is thought to have occurred since 1750. Questions must then arise as to the observed shape of the typical temperature records as represented by

Figures 3.42 and 3.46. How is it possible to reconcile the flat and then the exponential growth rate curve of the 'main climate driver', CO_2, with a rapidly varying surface temperature graph? Can such large and cyclic variability be possible, if natural variability really has only a 2.1% impact of the changes in the last 267 years? There appears to be very little connection between the alleged CO_2 growth curve and the rapidly varying measured and proxy temperature graphs. Difficulties arise with the stated overall solar total solar irradiance (TSI) forcing of 0.05 W/m² in AR5; because when the scientific literature is examined, very different numbers are found there (Yndestad & Solheim, 2017) (Herrera, Mendoza, & Herrera, 2015) (Y.-M. Wang et al., 2005).

3.6.3.1 The IPCC's small TSI forcing since 1750 is strongly disputed

An alternative TSI reconstruction, resulting in a large TOA variability, and a range of over 5 W/m² since 1700 (Figure 3.69).

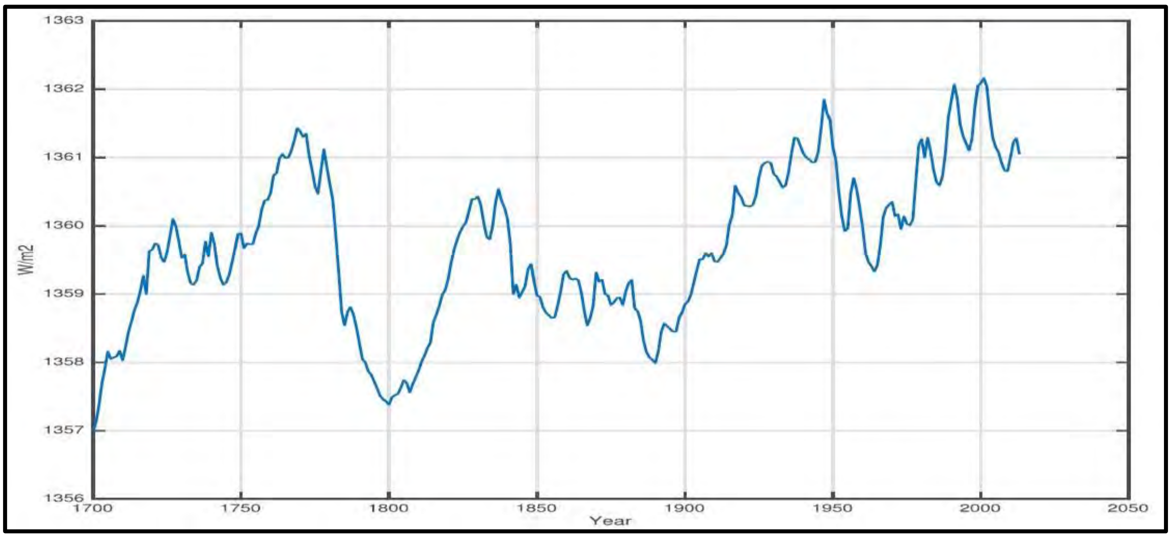


Figure 3.69 TSI reconstruction 1700 - 2013 (Scafetta & Willson, 2014)

Even though the Sun is obviously very important to climate changes on Earth, very few solar specialists or astrophysicists have been used by the IPCC. Astrophysicist Judith Lean has been a strong contributor to the IPCC process for many years; but for many years she was the only astrophysicist contributor. And over time, her long-term proxy TSI records have generally reduced in variability and become 'flatter' - compare 1998 (Fröhlich & Lean, 1998) to 2005 (Y.-M. Wang et al., 2005). The 2005 paper's TSI results is what AR4 based its solar variability on, which showed a change of little more than 1 W/m² in TSI since 1750 (Figure 3.70).

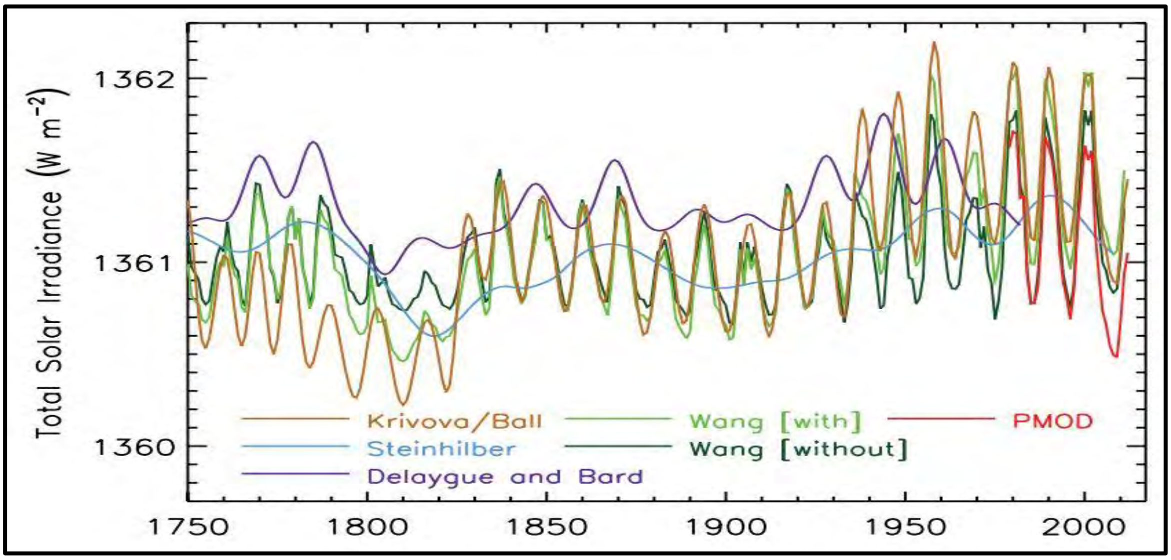


Figure 3.70 Reconstructions of TSI since 1750 in the IPCC's AR5 (Team et al., 2014)

In contrast, another TSI reconstruction (Scafetta & Willson, 2014) (Figure 3.69) shows a large variability of 5 W/m² over the same time period. This is based partly on whether the researcher uses PMOD or ACRIM TSI composites for a base TSI level. An ACRIM-based reconstruction, 1000 AD – 2100 AD by Herrera et. al. (Herrera et al., 2015) show an even bigger TSI range. The deepest part of the LIA in 1690 is shown as being ~7 W/m² lower in TSI than it is now, this much larger range confirms previous work by Shapiro (Shapiro et al., 2011) (Figure 3.71). A TOA range of ~7 W/m² points to a surface TSI change of +1.2 W/m² over the last 325 years, which is a factor of 24 times greater than the TSI change of +0.05 W/m² which is used by the IPCC in AR5.

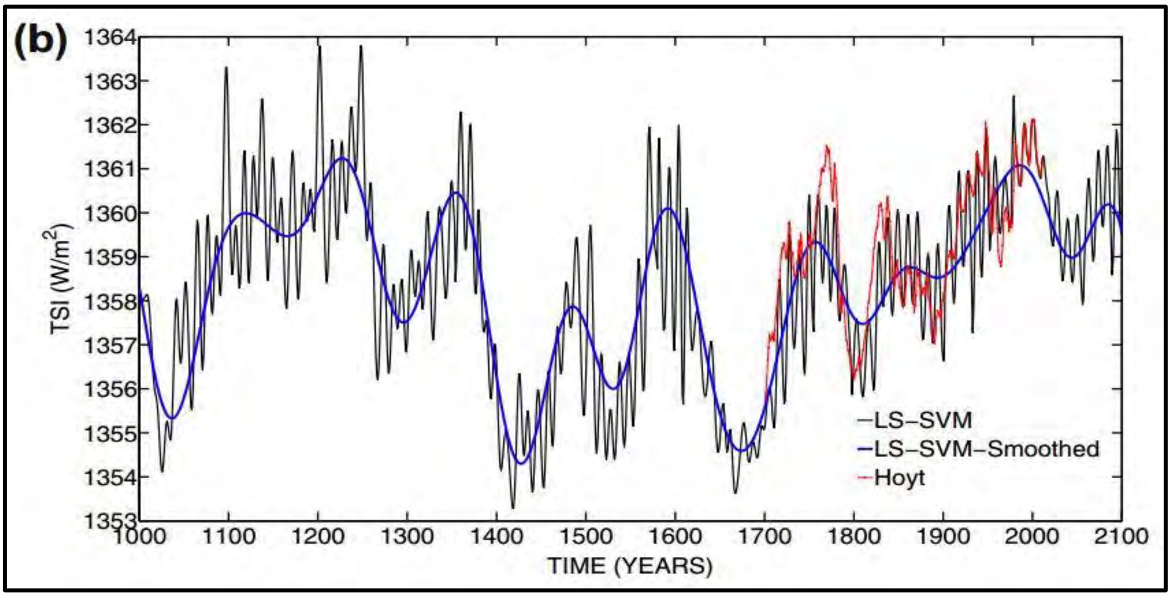


Figure 3.71 ACRIM based model 1000 AD – 2100 AD (Shapiro et al., 2011)

The only conceivable explanation for the LIA cold period that was centred on 1690, other than changes ultimately caused by the Sun, is large volcanic outbursts, of which there is no record. On balance, it is likely that the latter TSI reconstructions are the correct ones; it is known that ~1690 was the deepest part of the LIA or Maunder minimum. This extended from 1645 to 1715 (Ribes & Nesme-Ribes, 1993) and was the period in history with the lowest solar activity ever recorded; there were many years without any observed sunspots. After 1715, that there was a sudden and strong rise in solar activity, - and in global temperatures, between then and 1750. This temperature rise could not have been caused by human activity, yet was greater in size and similar in rapidity to the 'unprecedented' late 20th century temperature rise. This early 18th century climate change is seen in many solar proxy climate records; (Figure 3.19) and is also clear in the planet's oldest continuous thermometer surface temperature record, the central England air temperature record (CEATR) which commenced in 1659 (Figure 3.72).

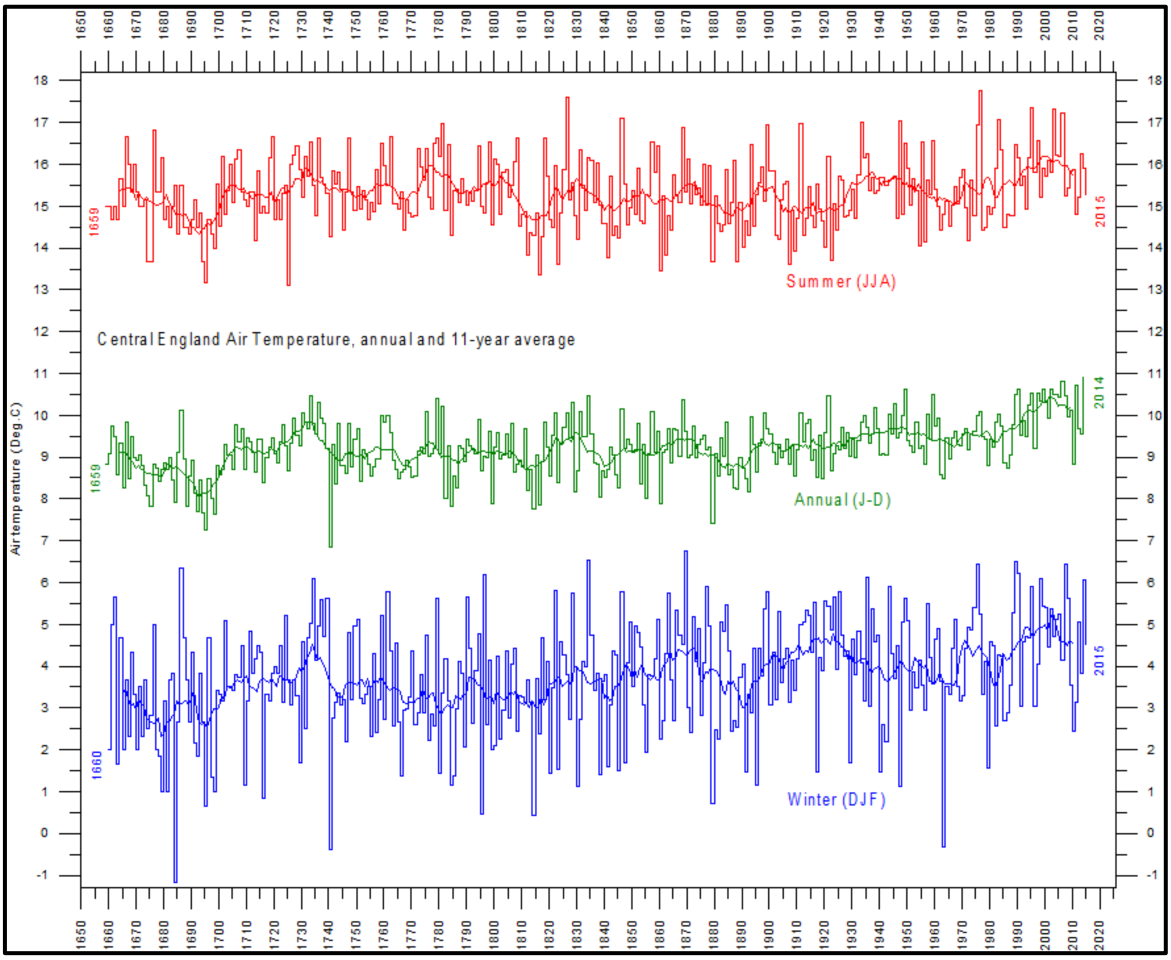


Figure 3.72 CEATR; measured temperatures since 1659 (Climate4you, 2017; CEATR)

The ‘pre-industrial’ starting date of 1750 as used by the IPCC, appears to be arbitrary; if 1700 is used instead, and it was also thought that Scafetta and Wilson’s reconstruction was the better one, then a TSI change of 1,357 W/m² to 1,361 W/m² would be more realistic, which is net change of ~4 W/m². Dividing by 4 to allow for the surface area of the Earth and multiplying by 0.7 to allow for the albedo, a solar surface radiative forcing change of +0.7 W/m² is realised; that is, a factor of 14 more than is allowed for by the IPCC in AR5. This is noted here not to criticise the IPCC’s reports unduly, but to be illustrative of the huge uncertainties which still abound in the field of climate change.

3.6.4 The Holocene climate optimum and other recent warm periods

Earth is in an ice age, and has been for ~2.6My (Kim, Nam, & Bang, 2012); but humanity is currently fortunate enough to be in a warm interglacial period, the Holocene. Inter-glacials typically last 10ky – 15ky and the Holocene started 11.5kya, and so the present could well be near the end of it. The warmer part of the Holocene climate optimum spanned thousands of years and peaked ~6kya; proxy records show that it was warmer than the present period by ~0.65°C or more (Rosenthal et al., 2013). The Holocene has been an amazingly stable climatic period compared to the wild climatic variability seen in proxy records from the preceding 90ky of glaciation. Human civilisation has made rapid advances from the hunter-gatherer stage during the Holocene, leaving the Stone Age, entering the Bronze Age and becoming farmers. The Iron Age soon followed, and vast cultures arose in several places, many of them became sedentary and established permanent settlements. It is unlikely to be coincidence that these advances took place during a period of relative warmth and climate stability; in fact, studies show that it is during warm periods that civilisation advances (H. F. Lee & Zhang, 2013) and which are times of plenty, and it is during cold periods when there is extreme weather, famine, war (Gartzke, 2012) and pestilence.

3.6.4.1 The Anthropocene

The proponents of EGGWH insist that humans have so changed the global temperature and so the climate, that the Earth has now entered a new period; The ‘Anthropocene’ (Steffen, Grinevald, Crutzen, & McNeill, 2011) (Zalasiewicz, Williams, Haywood, & Ellis, 2011). The Anthropocene has not been formally declared, or even defined as a geological unit yet, but there is no doubt that many proponents of the idea consider human influence on the Earth and its climate system to be so large that a geological signal is being laid down in the strata. Among proponents of the change in name, human-induced changes on the Earth are almost universally seen to be a very negative influence; much of this relating back to human CO_2 emissions and their role in global warming. It goes perhaps without saying that a relatively small change in atmospheric CO_2, measured in hundredths of one percent, cannot possibly cause climate change by itself; it must first cause a significant atmospheric temperature change. And radiative gas physics also says that that aggregate human GHG emissions also cannot cause dangerous climate changes by themselves; their effect must be substantially magnified by positive feedback, and then cause a strong and unusual atmospheric temperature change first.

3.6.4.2 Testing whether the current warming period is unusual

An initial test as to whether there has been any unusual warming due to human emissions, will be to compare the measured climate record where there might have been a human influence, with historical proxy climate records, where there cannot have been a human influence. In this way, it will be able to be ascertained;

i. whether or not the current climate record is outside of the average range of natural variability, and;
ii. if it is, is there any evidence that the warming had a mostly human cause?

Apprising Figure 3.6 from AR5, the relative radiative climate forcing chart, it is stated that net anthropogenic forcing on the climate system far exceeds all natural climate forcing's – at least since 1750. The typical climate model, (Figure 3.5) has those relative climate forcing's inbuilt, and so faithfully represents this scenario in its projections. When the hockey stick curve was published (Mann et al., 1998), (Figure 3.7) it seemed to confirm this, and appears to show the current period of global warming to be well outside the past range of natural climate variability – so highlighting consideration (i). And when this was combined with the CO_2 record from Moana Loa, then consideration (ii) was highlighted; could this be the evidence of both an unusual warming, and a human cause that has been long sought?

3.6.4.3 Other proxy temperature curves, covering the last 2ky

The CRF and temperatures in Figure 3.18, are well correlated, and the long-term solar activity proxy, ^{14}C in Figure 3.22 takes a sudden turn upwards to a peak in the late 20th century, lending support to the existence of an unusual, but natural event which drove the warming. Proxy temperature graph Figure 3.44 shows a strong peak occurring in the late 20th century, but perhaps not an unusual one; and the earlier natural variability is much greater than that shown in the hockey stick curve, leading to the conclusion that more information on this period is needed. The HadCRUT3 surface temperature curve in Figure 3.48 gives little support to the very sudden and unusual change seen in the hockey stick; neither do comparisons between tree ring and other proxies, such as stalagmites. The tree rings show a range of variability which is seven times smaller (Horst-Joachim Lüdecke, 2011), leading to the possibility that this flatness is a feature of the tree ring proxies.

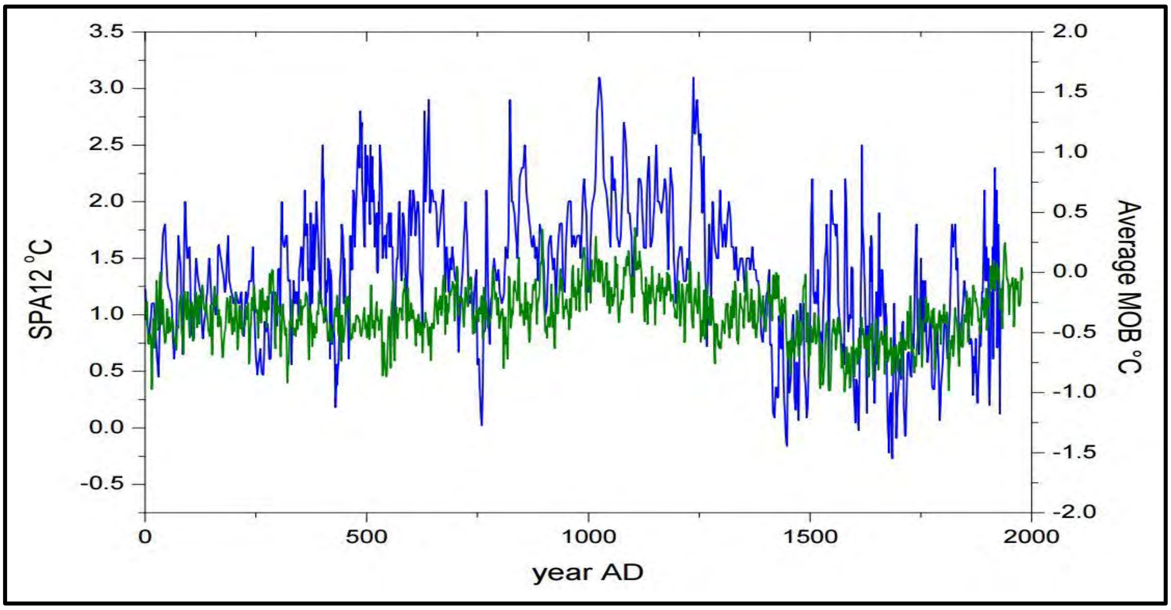


Figure 3.73 NH; tree rings green, stalagmites blue, (Horst-Joachim Lüdecke, 2011)

Since HadCRUT3 is thermometer measurements and the hockey stick is taken from a proxy (tree rings) the former should be given preference; tree rings generally show less climate variability (Figure 3.73). The unusually high level of late 20th century solar activity suggested by several solar activity proxies, lends support to natural variability significantly contributing to the observed late 20th century rise in global temperatures (Figure 3.66).

3.6.4.4 Scientific evidence that the current warm period is not unusual

A recent study of Holocene climate changes in Asia, lends support to the proposition that the present global temperatures are nothing unusual (Aizen et al., 2016), and are lower in fact, than the majority of the Holocene period. (Rosenthal et al., 2013). Recent research indicates that the MWP, especially around the year 1300, (just 700ya) was 0.5°C warmer than the present is, in Scotland (Rydval et al., 2017) and in China (H. Zhang et al., 2015). Rydval et. al's temperature reconstruction from Scotland reveals that the warmest 5 years since 1200 were, in order; 1284, 1285, 1307, 1310 and 1282. Their reconstruction shows that the CWP was easily exceeded by the MWP centred on the year 1300 and is similar only to several other more recent warm periods such as the ones around 1500, 1730, 1880 and 1940 (Figure 3.74). The De-Vries / Suess climate cycle, which peaks approximately every 210 - 240 years is clearly represented in this reconstruction, as it is in several others; the ~61 – year Yoshimura climate cycle with recent peaks in 1880, 1941 and 2002 is also apparent.

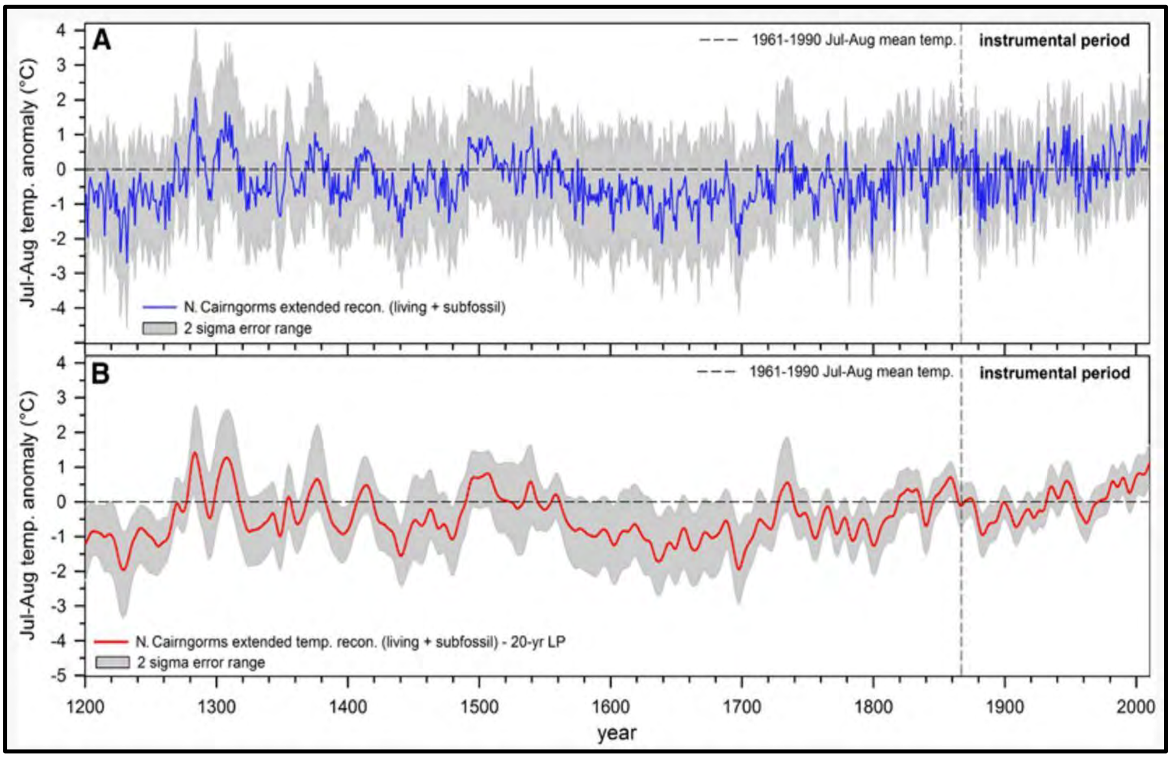


Figure 3.74 Reconstructed temperature in Scotland since 1200 (Rydval et al., 2017)

There is considerable evidence that both the RWP the MWP were warmer than the CWP and were global; South China Sea temperatures (Yan, Sun, Shao, Wang, & Wei, 2014); China in 1300 (H. Zhang et al., 2015); Central European temperatures in 1540 (Orth, Vogel, Luterbacher, Pfister, & Seneviratne, 2016); Middle East temperatures, 900 – 1900 (Kaniewski et al., 2011); European Alps (Ladurie, Delibrias, & Ladurie, 1975) (Lamb, 2013), Australia (Tozer et al., 2016), Tibet (He et al., 2013) the Pacific and Atlantic oceans (Rosenthal et al., 2013). An interactive map has been constructed by Professor Vahrenholt and Professor Luning which lists the mass of 951 published scientific papers underpinning the robustness of the MWP (MWP, 2017) from every corner of the globe. This leads to the inescapable conclusion that the CWP is well within the range of natural variability.

3.6.5 Investigating historical CO_2 levels

3.6.5.1 Comparing historical CO_2 levels to historical temperatures

The historical atmospheric level of CO_2 needs to be compared to these reconstructed temperature charts, because according to the IPCC's AR5, CO_2 is the main climate driver; in fact, an incremental change in atmospheric CO_2 causes an incremental change in global temperatures, (Figure SPM.5, b; Figure 2.1 and Table SPM.1) in the AR5 synthesis report (Allen et al., 2014). However, when the CO_2 data taken from ice cores is examined, such as Law Dome in Antarctica, (Figure 3.75) there is only a slight variation in the record pre-1750 of ±5ppm. According to this direct ice core gas measurements, the pre-industrial range was 275-284ppm from 1006A.D. to 1750A.D. (Etheridge et al., 1996). Other ice core CO_2 data from GISP2 in Greenland agrees with this conclusion (Barnola et al., 1995). If CO_2 had little variability, and CO_2 is the main climate driver, does it make sense that a large variability in temperatures, is seen in many proxy reconstructions? (Figures 3.43, 3.44, 3.64, 3.65, 3.68, and 3.74)

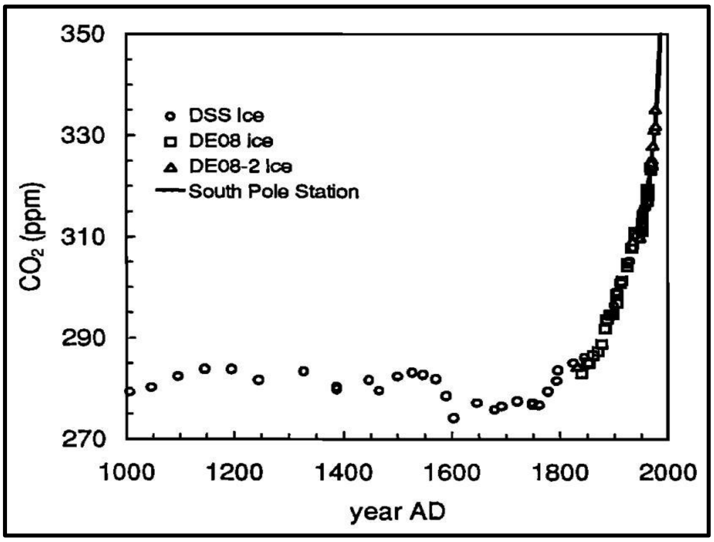


Figure 3.75 Ice core CO_2 from Law Dome in Antarctica (Etheridge et al., 1996)

It must also be noted that the CO_2 level in the Law Dome ice core record, definitely started to rise by 1770; this rise has been uninterrupted since then until the present. Now the total anthropogenic CO_2 emissions which occurred before 1870, constitute less than 1% of man's total CO_2 emissions to date; yet atmospheric CO_2 concentrations had already been rising for a century by then (MacFarling Meure et al., 2006). Man could not have been responsible for that rise. Law dome atmospheric CO_2 actually increased at ten times the rate of cumulative anthropogenic emissions 1751-1875 (MacFarling Meure et al., 2006).

This rise can make sense though, when Henry's law is considered, along with the sudden global warming in the period 1690 -1750. Given the large range of natural climate variability that is seen in the period 1200– 1750 and the small range of atmospheric CO_2 variability from the ice core record, there can be no causal link during this period in the direction of CO_2 to temperature variability, because if there was such a link, the climate sensitivity must be far higher than anything that is possible. Therefore, the causal link must be in the other direction that of global warming causing a CO_2 rise. There are many papers in the literature supporting such a link, both in the present decades (Humlum et al., 2013) and during the last glacial period (Caillon et al., 2003); physics also strongly supports such a link through Henry's law (Weiss, 1974). In this context, the CO_2 and the temperature data post-1690 examined together, testify that the climate sensitivity cannot be high and it cannot be moderate, it can only be low, very low, zero or negative.

3.6.5.2 A 2ky climate context is needed

One of the main problems in all the IPCC's reports is a lack of context. Their charts and reconstructions virtually all start either in 1850 or in 1910. Firstly, these are known lows in the temperature record, and so measuring any temperature rise from these points is misleading. Secondly these starting dates do not allow sufficient time for context in terms of natural climate variability and to allow for the existence of century-scale or longer climate cycles to become clear.

3.6.5.3 Was all the increase in atmospheric CO_2 since 1750 caused by man?

A firm claim which is made by EGGWH proponents, and by the IPCC in its reports, is that 100% of the purported rise of 120ppm in atmospheric CO_2 since the 'pre-industrial' level of 280ppm in 1750 has been caused by man. Is this possible, considering Henry's law states that when the ocean warms, CO_2 is expelled? These same proponents say that the oceans have been warming over this period; how could the oceans warm, and yet not expel more CO_2 than they take in? A second problem arises with the pre-industrial level of 280ppm in 1750. This claim relies wholly on the ice core record for CO_2, which shows an atmospheric concentration varying between 180ppm and 300ppm over the last 800ky (Lüthi et al., 2008) (Figure 3.76).

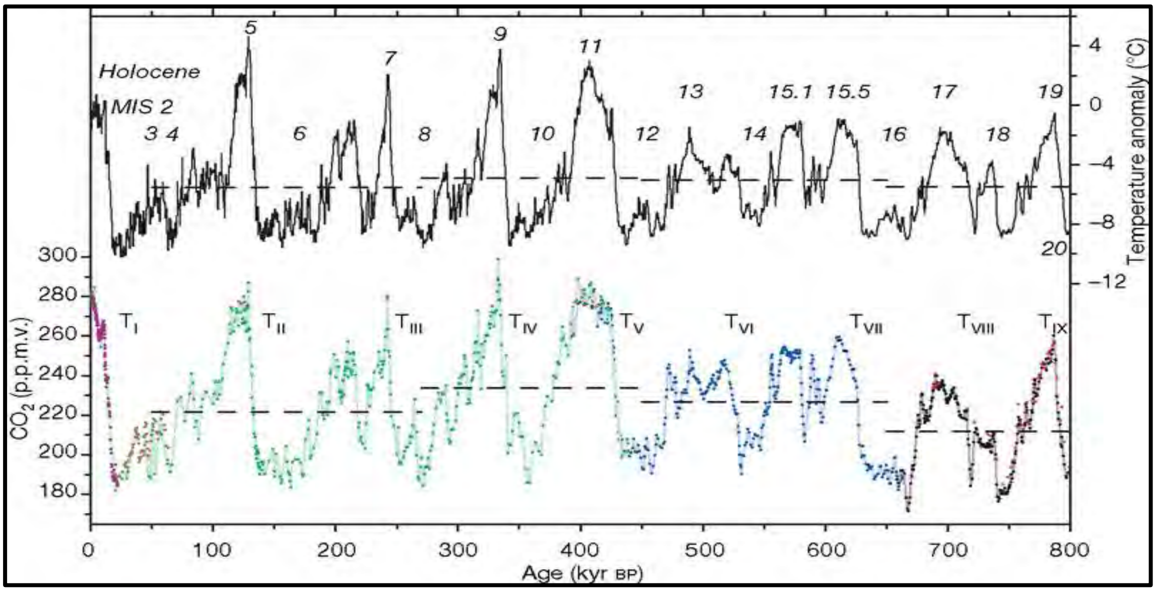


Figure 3.76 Ice core CO_2 bottom, temperature proxy ^{18}O top (Lüthi et al., 2008)

It is noted in all ice core records of CO_2 that it is monotonic on century time-scales. It does vary substantially between 180ppm and 300ppm over multi-thousand-year periods in the ice core record, but shows very little short-term variability. Has there really been little short-term atmospheric variability, or is this monotonic record for CO_2 simply a feature of the ice core record itself? This important point has not been sufficiently explored in the literature.

3.6.5.4 Other CO_2 proxies such as plant stomata show >400ppm CO_2

To check on this, there is a need to look at other CO_2 proxies, for example, plant stomata. The issue is that there are other proxy records for CO_2, which are ignored in the IPCC reports, and often also by advocates of EGGWH; these include plant stomata proxies. Stomata are small holes in leaves where plants take in their food, which is CO_2. It has been shown by researchers that when CO_2 is abundant in the atmosphere, the stomata react by shrinking; they do this in order to prevent loss of moisture from the leaves. When there is little atmospheric CO_2, stomata grow larger in order to take in sufficient food. Plant stomata proxies show that CO_2 was around 400ppm as recently as 450A.D. (Kouwenberg, 2004) (Figure 3.77). The monotonic CO_2 ice core record is also shown, as small squares.

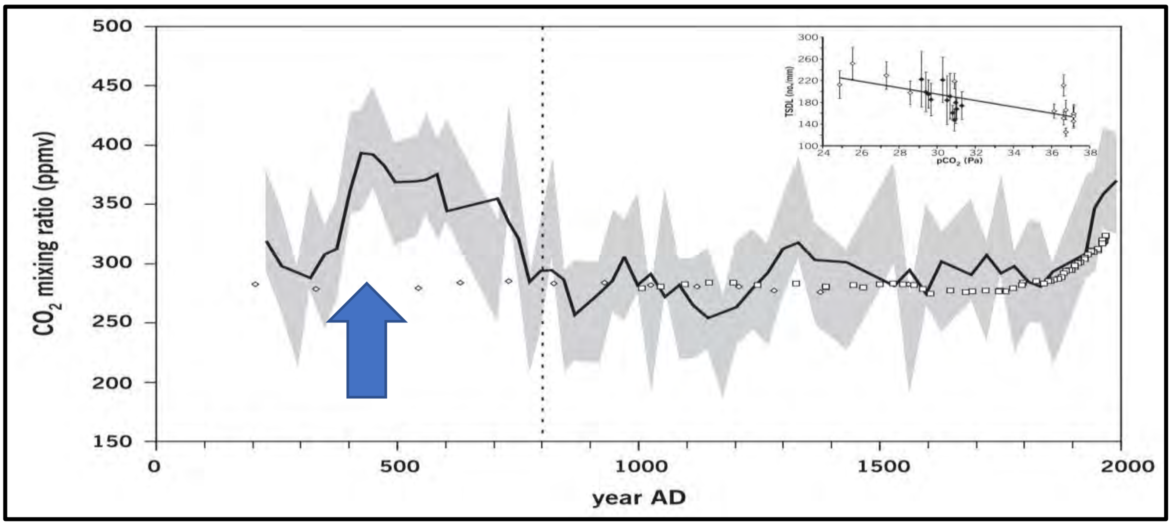


Figure 3.77 Plant stomata CO_2 data over the last 1800 years (Kouwenberg, 2004)

This plant stomata record was calibrated against current similar stomata. The proxy shows a rise to above 400ppm around 400A.D. and this is delayed from a matched rise in the global temperature proxy isotope ^{18}O in the period 350 - 600A.D. which is also clear in the GISP2 record (Alley, 2000) (Figure 3.78). There is also a significant delayed bump in the stomata CO_2 data relating to the MWP around 1300. The CWP is also visible, with temperatures rising from ~1860, with the delayed CO_2 bump from ~1900.

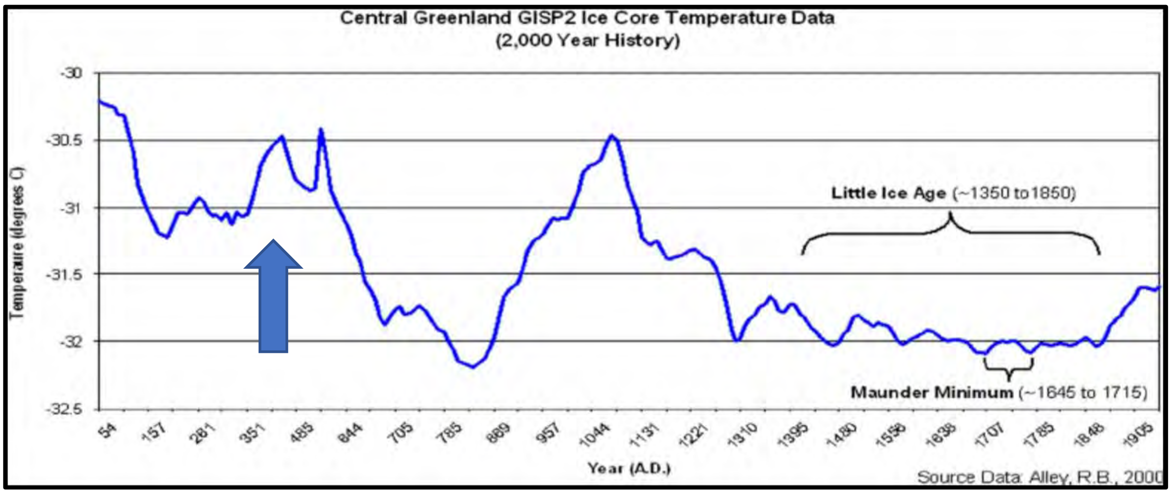


Figure 3.78 GISP2 ice core temperature proxy ^{18}O over the last 2ky (Alley, 2000)

A temperature proxy (Liu, Cai, Song, An, & Linderholm, 2011) from the Tibetan Plateau also shows a sharp temperature peak ~400A.D. along with other familiar features, such as the MWP, the LIA and CWP (Figure 3.79). These authors also found several climate cycles, and used these to project a cooling period (in red) starting now with a low in 2068. They also found that the largest temperature changes to occur in the last 2ky was not in the 20th century, but in the 82y period 343 – 425A.D. They attribute the late 20th

century warming to the overlapping of multiple short climate cycles, underpinned by the peaks in longer millennial-scale climate cycles. This is a familiar result, as will be seen from other research.

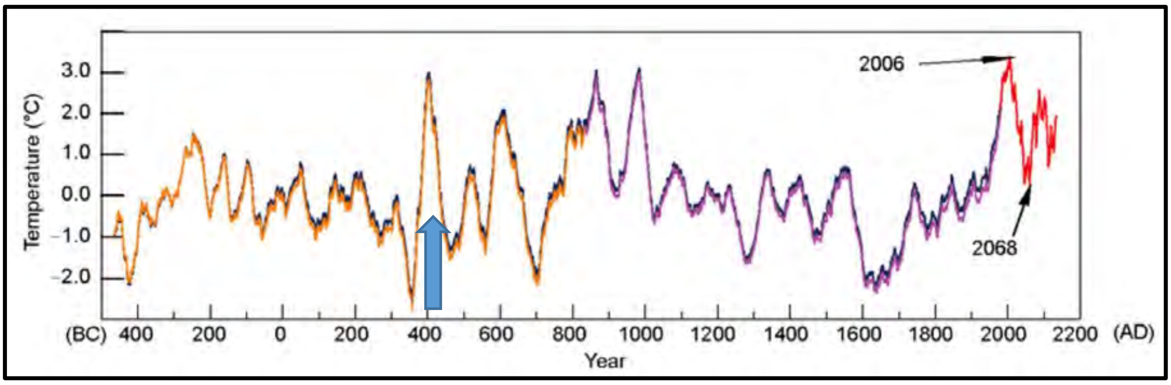


Figure 3.79 Tibetan plateau climate record (Liu et al., 2011)

If other records are examined, for example dwarf birch stomata in Sweden (Steinthorsdottir, Wohlfarth, Kylander, Blaauw, & Reimer, 2013) (left, Figure 3.80) it is found that this proxy for CO_2 goes well over 400ppm just before the Holocene era started, around 13kya, and was highly variable between 200ppm and 420ppm around the Younger Dryas period. The ice core record (from EPICA Dome C) is much flatter, moving in a small 20ppm range with long, slow changes from 235ppm to 255ppm (right, Figure 3.80).

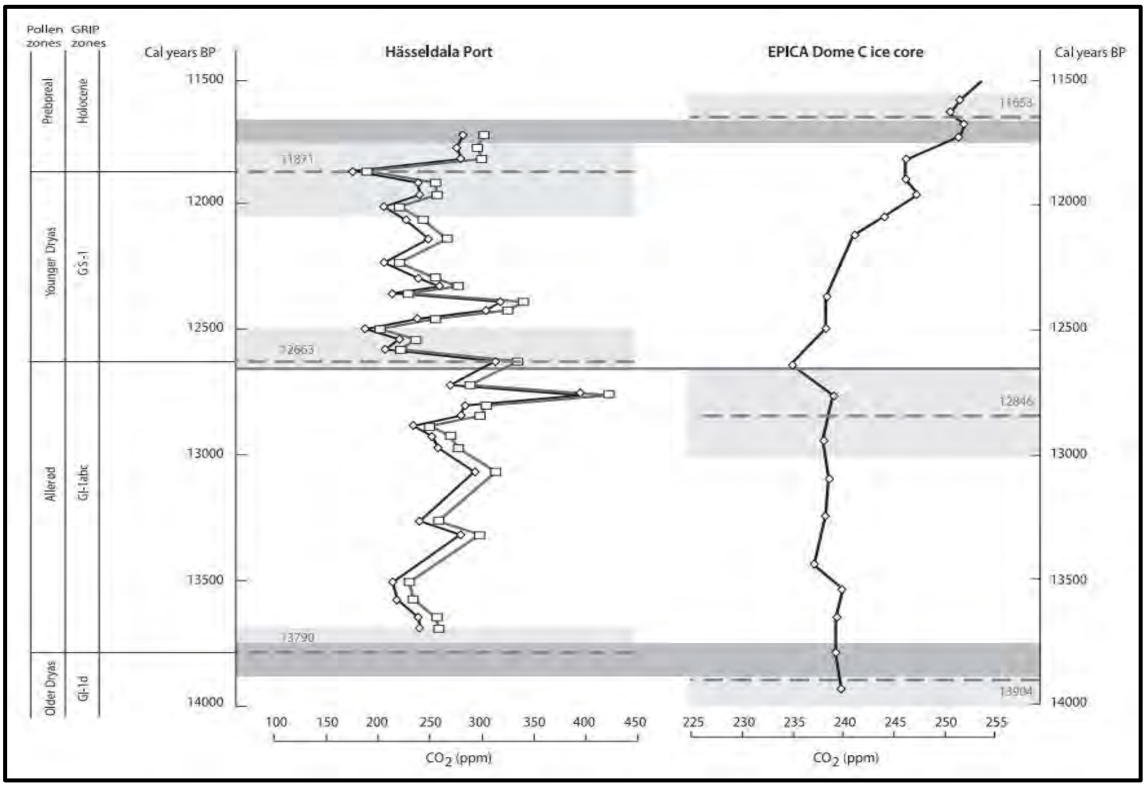


Figure 3.80 Stomatal birch vs Antarctic ice core data (Steinthorsdottir et al., 2013)

There is a mystery, why does the plant stomata show a highly variable record for atmospheric CO_2, changing by 220ppm, while the ice core record from the same period shows a monotonic record, varying by just 20ppm? Both cannot be representative of global atmospheric CO_2 changes. The answer may be related to the Knundsen diffusion effect (Kowalewski, Marchant, Levy, & Head, 2006) (Johnsen et al., 2001) (Jaworowski, Segalstad, & Ono, 1992), which is a pressure-related diffusion that happens in the ice. Above a pressure of 300 bar, this diffusion may significantly affect the CO_2 record contained in the ice, effectively minimising variations by reducing maximums and minimums. The disassociation pressure for CO_2 may even start as low as 5 bar (Jaworowski, 1994). Very important questions are raised here, about whether the ice core record for CO_2 mirrors the true variability and the true maximums of historical atmospheric CO_2 levels.

This question goes back to Callendar (1938) who estimated the 19th century level of CO_2 to average 292ppm by selecting from data by compiled by Fonselius et. al., (1956). The selection method was questioned by Slocum (1955) who stated that without this method, the average 19th century level for CO_2 from the data would be 335ppm. Further problems in the matching-up of the Siple ice-core levels (Neftel et. al., 1985) with the start of the Moana Loa measurements of CO_2 were pointed out by Jaworowski (1994) where the unadjusted Siple data showed 328ppm in 1891. It seems that the data was then shifted 83 years forward, and the end result was a better match up with the measured atmospheric concentration from Moana Loa. Other difficulties with the ice core record of CO_2 surround the Vostok record, which shows CO_2 remaining well below 200ppm for tens of thousands of years (Barnola et. al., 1987). Such low levels of CO_2, for this extended period of time, should have caused the extinction of certain plant species (Sarmiento, 1991) (McKay et. al., 1991), of which there is no record.

3.6.6 Alternative views on climate sensitivity to CO_2

As mentioned earlier. the answer to the key question, as to whether anthropogenic CO_2 emissions need to be radically cut, or need to be slowly reduced, or really need no immediate action at all, depends entirely on the climate sensitivity. The alternative view to the IPCC's range of climate sensitivity, are mainly the non-mainstream views. These scientists argue that either;

a) the larger part of the 1950-2017 warming was natural variability
b) there is no positive feedback to CO_2 from water vapour
c) the greenhouse effect itself is much lower than is shown in IPCC reports

d) the climate sensitivity is so low that it is net beneficial

Papers typical of falling into category 'a' is work by Harde (Harde, 2014) who calculates a climate sensitivity of just 0.6°C, and a contribution thus far from man to global warming of only 0.2°C. He notes that solar activity was higher in the last half of the 20th century than it has been for at thousands of years (Usoskin et al., 2007) (Steinhilber et al., 2012).

Papers in category 'b' would include those by well-respected scientists such as Richard Lindzen (Lindzen & Choi, 2011) (Lindzen & Choi, 2009) and Roy Spencer (R. W. Spencer & Braswell, 2011) who use satellite data in their arguments, which they say prove that the feedbacks from water vapour are very low or even negative. There is also direct contradictions between papers here, for example Ramanathan & Vogelmann (Ramanathan & Vogelmann, 1997) who insist that their modelling proves that the forcing which is added to the climate system directly by anthropogenic GHG is 0.5 W/m^2/decade, and that positive feedback is to be added to this as a multiplier. However, later direct atmospheric measurements by Feldman et. al., (Feldman et al., 2015) show that the main GHG, CO_2 currently adds just 0.2 $W/m^2 \pm 0.06$ W/m^2 per decade to the greenhouse effect.

Some papers with an interesting background, fall into category 'c' such as the work on planetary atmospheres by "Den Volokin & Lark ReLlez" initially published by the journal 'Advances in Space Research' in 2015 and then withdrawn (Volokin & ReLlez, 2015). The authors were in fact later exposed by Gavin Schmidt, (the head of NASA's GISS since 2013) as actually being Ned Nikolov & Karl Zeller, both of whom work for the U.S. department of agriculture as a physical scientist and a meteorologist, respectively. Yes, they tried to cover their identity by spelling their names backwards; this could be seen as one of the more interesting episodes in what many think has become a politicised field. Nikolov and Zeller have published similar work to that which was withdrawn, this time under their own names (Principles et al., 2011). This paper is an extended version of a poster which they presented at the open science conference of the world climate research program in Denver CO, in 2011 and is interesting for its detailed physics of planetary atmospheres. The work essentially disputes the strength of the greenhouse effect in all thick planetary atmospheres, on the basis that the lower atmospheric heating which the IPCC associates with the greenhouse effect is in fact generated mostly by adiabatic auto-compression and not by the radiative greenhouse effect at all.

In category ‘d’ are Kissin (Kissin, 2015) and (Abbot & Marohasy, 2017) they estimate climate sensitivity to be between 0.5°C - 0.7°C. Kimoto (Kimoto, 2015) disputes the Planck response of the climate system to the initial forcing from CO_2; he calculates a very low climate sensitivity of 0.17°C.

3.6.7 Reliance on climate models

Well represented in the climate literature and highly visible in all the IPCC’s reports are the results of many climate models. Often, it is the projections of these models, along with estimates from paleoclimates from which final estimates of climate sensitivity are made; this is where the AR4 arrived at 3°C as its best estimate of ECS. A model’s output depends entirely on its inputs and its ability to accurately model the climate system, and if either the relative climate forcing is wrong or the model’s ability to model the climate system is poor then the output is also going to be inaccurate. Unfortunately, the current generation of models are very far from modelling the climate system accurately in many areas, but especially with regards to the action of clouds (Vavrus, 2004). The problem of clouds also figures in the inability of climate models to accurately model back-radiation from GHG – something that should be a basic skill in models designed to model the greenhouse effect. Modelling periods of more than 2 months, reveal that models are sometimes >10 W/m² out across all areas, and up to 50 W/m² out in estimating downward longwave radiation in the Antarctic (Morcrette, 2002). The scale of these errors is brought into focus when it is realised just how small the incremental anthropogenic forcing that is being measured. The net anthropogenic forcing on the climate system is said to be 2.3 W/m² over the period 1750 – 2011 (Team et al., 2014). If this is just averaged (for simplicity) over the 261-year period then the annual forcing would be 0.0088 W/m², and over a 2-month timeframe would be 0.001 W/m²; which is 10,000 times smaller than the minimum reported error. Also, providing context to the small size of the incremental anthropogenic forcing, is the natural and regular change in insolation from eccentricity, which changes TOA insolation by 92 W/m² every 6 months (and so by 16.3 W/m² on average at the surface).

This known natural change is more than 1,000 times the alleged averaged anthropogenic climate forcing, over the same 6-month period. Other large natural changes in the Earth’s radiative balance occur in the OLR; the anomaly can change by 80 W/m² within a year (Figure 3.60). These numbers supply a clue as to why it has been so difficult to measure the actual effect that humanity's emissions have on the climate system.

3.6.8 Downwelling longwave radiation

Of course, the OLR (Figure 3.60) is well known, measured regularly by satellites, and also comes from common physics – the Earth is expected to absorb and then re-emit radiation depending on its temperature. The EGGWH also says that downwelling longwave radiation (DLR) exists; this is the portion of the OLR which is captured by the atmospheric GHG, and then is re-emitted in all directions equally – meaning around 50% of it returns to the surface. This radiation is expected to be in the thermal infra-red spectrum, in the wavelength band from 4µm to 100µm.Since this radiation is downwelling, it cannot be measured by satellites and must be measured from the ground by pyrgeometers (Wacker, Gröbner, Hocke, Kämpfer, & Vuilleumier, 2011). DLR or 'back-radiation' is one of the main constituents of the global energy budget according to proponents of the EGGWH (Trenberth, Fasullo, & Kiehl, 2009) and averages 333 W/m² which is then 'absorbed by the surface' (Figure 3.81).

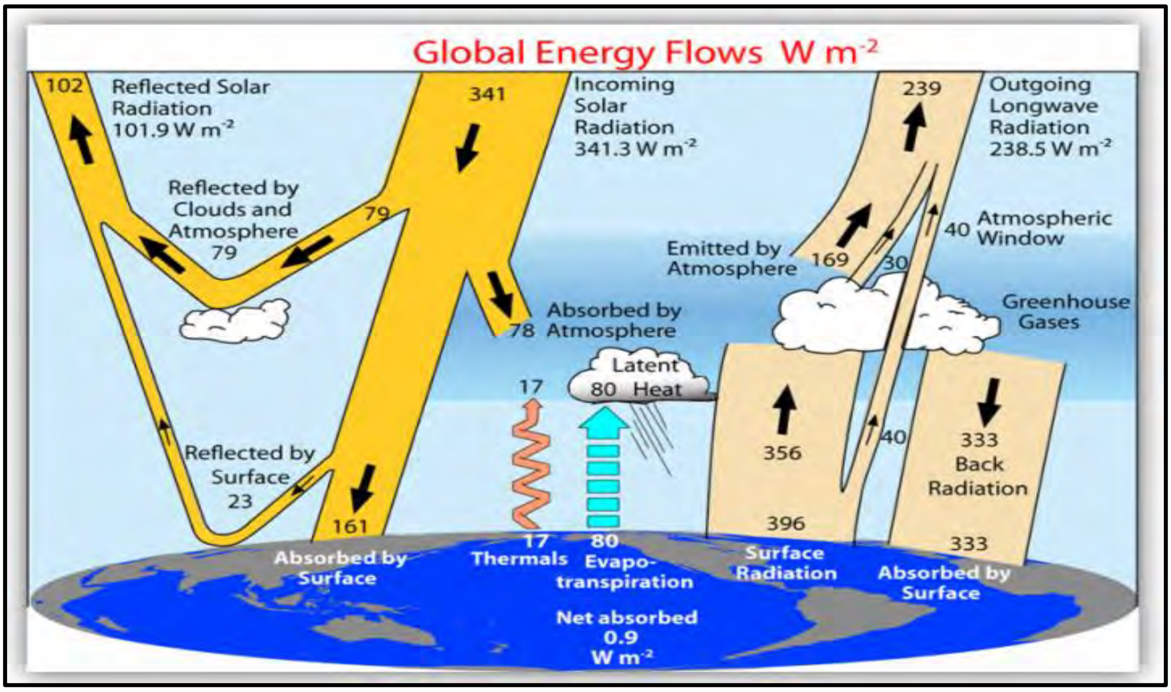


Figure 3.81 Back-radiation is 333 W/m² according to Trenberth (Trenberth et al., 2009)

On these figures, the DLR from atmospheric GHG exceeds by a large margin the energy input from the Sun, which is stated to be ~239 W/m². Something appears to be wrong with this picture; it is stated that 356 W/m² +77 W/m² +17 W/m² + 80 W/m² = 530 W/m² is absorbed by the atmosphere. If all this is absorbed and then re-emitted, logic says that no more than 50% will be re-emitted downwards, which is not more than 265 W/m². Also, it seems to be unphysical that radiation emanating from a colder atmosphere could warm a warmer land or ocean surface. Already explored are the difficulties that long-wave radiation would have warming the oceans (Irvine, 2014) (Figure 3.61).

3.6.9 Emission curves of Earth and the Sun compared

However, there is definitely some 'excess' heat in the lower atmosphere; this has been measured, and comes from S-B arguments about the emission temperature of Earth given its energy input from the Sun – which was previously calculated to be 255.59K. This is known as the effective emission temperature for Earth, and it has a related effective emission height (which on an airless black body is the surface) in the atmosphere. This emission height gets higher - if the lower troposphere warms up. The actual average temperature of the surface of Earth is ~288K, the Sun is 5,800K. Maximum emission wavelength is given by Wein's law;

$$\lambda_{max} = 0.0029/T \tag{15}$$

$$\text{Earth} = 0.0029/288$$

$$\text{Sun} = 0.0029/5777$$

$$\text{Maximum emissions wavelength (Earth)} = 10\mu m$$

$$\text{Maximum emissions wavelength (Sun)} = 0.5\mu m$$

These emission peaks are depicted in Figure 3.38. This type of representation of the respective emission curves of the Earth and the Sun, showing no overlap, is widespread but could be misleading. It is possibly done so that the two curves can be compared conveniently side-by-side, but in actuality the Sun's curve peak is in fact several million times higher than Earth's – but more importantly, has a much greater spread than is shown.

A more accurate depiction is seen in Figures 3.82 and 3.83, which clearly show that the black body emission range of the Sun includes the entire emission range of the Earth and extends far beyond it. This is important because one of the main arguments behind the EGGWH has been that GHG are not affected by short-wave insolation from the Sun; while true, this statement leaves out the fact that some direct insolation from the Sun is in fact long wave radiation. The atmosphere does absorb some direct insolation, about 77 W/m² according to Trenberth et al, as shown in Figure 3.81. The figure also includes 256 W/m² of upwelling infra-red radiation, and 333 W/m² of downwelling infra-red radiation.

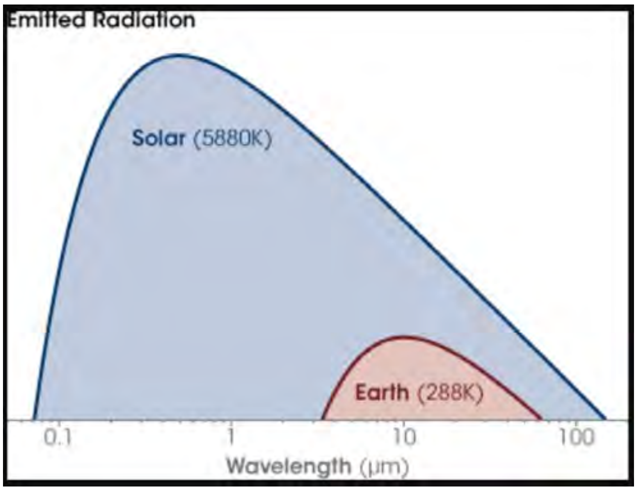


Figure 3.82 True black body emissions curves of Sun & Earth (NASA, black body)

The 77 W/m² of direct insolation absorbed by the atmosphere is quickly thermalised by the 99% of molecules which are not GHG, and so become kinetic energy in the atmosphere.

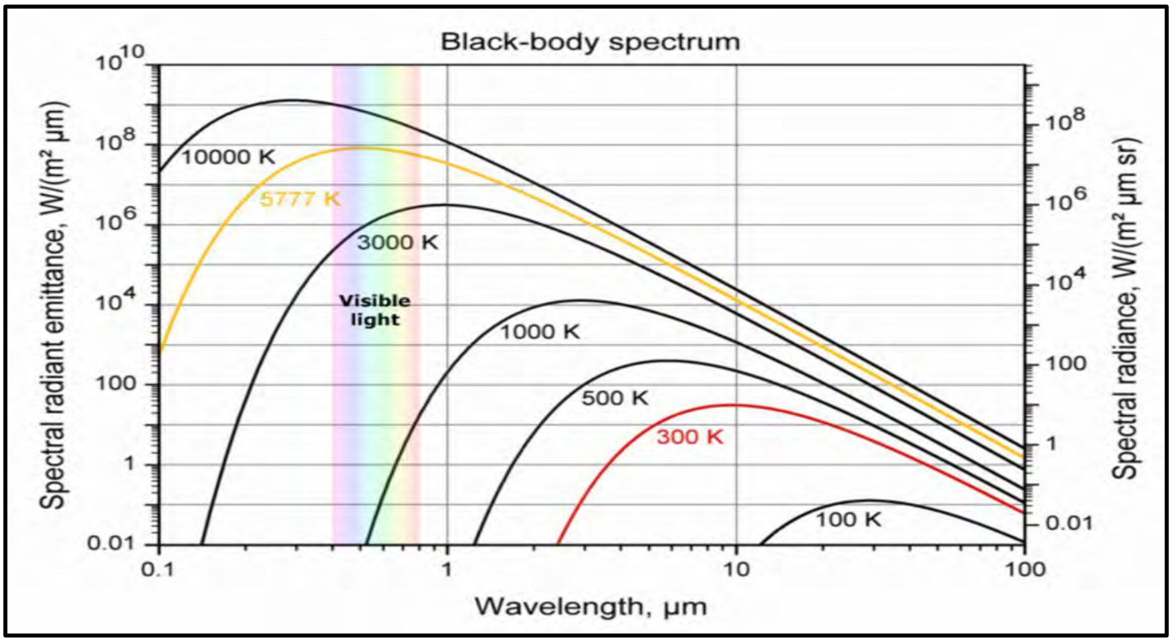


Figure 3.83 Black body emission curves 5,777K and 300K (Sun.org black body)

It is now time to explore the null hypothesis, its postulates and the possible features which are likely to be included in it.

3.7 The null hypothesis – an alternative to the EGGWH

Presented here is an alternative to the EGGWH; this is in fact, simply the null hypothesis (as defined in section 3.5). Why hasn't this been presented before now? Why wasn't this explored in the first place by the IPCC? The answers lie in two facts; that the field of climate science is a relatively new field which did not have a settled null hypothesis yet, and the political nature of the IPCC. It has just taken time to do the research and publish sufficient results in order to come to some sort of overall baseline conclusions – especially given that in many cases, the 'mainstream' thinking – and most of the research dollars spent in the field since 1988 has tended to be in one direction only, that of exploring man-made greenhouse warming instead of exploring the null hypothesis. The postulates of the null hypothesis (H_0) are presented here for hypothesis testing.

3.7.1 Ho; postulates of the null hypothesis of global temperature change

- That natural variability mainly determines the global temperature changes on Earth on all time-scales – in the present as well as in the past.
- That Earth's greenhouse effect, comprising natural and man-made GHG, contributes marginally to atmospheric warming at lower atmospheric levels an substantially to cooling at higher levels of the atmosphere.
- That a feature of all planetary bodies with thick atmospheres, such as Earth, is a pressure-induced atmospheric temperature gradient, created by adiabatic auto-compression, in which gas temperatures are found to rise consistently by a temperature measuring device as it descends from a gas pressure of ~10 kPa to the higher gas pressures which prevail in the lower atmosphere.
- That gravity-induced auto-compression and the effects of atmospheric convection form the temperature gradient in the troposphere, dominate over radiative transfers in that part of the atmosphere of Earth.
- That natural variability is dominated on all time-scales, by many climate cycles, (the literature mentions at least 16, these are listed in Table 3.4) which drive climate change on Earth through various mechanisms, not all of which are detailed yet in the scientific literature.
- That most of the shorter-term climate cycles (11yr Schwabe to 2,300yr Hallstatt) are astronomical cycles, which drive solar activity changes, the climatic effect of which on Earth is enhanced by a mechanism; the cosmic ray/cloud/albedo link.
- The three medium term Milankovitch cycles, caused by Earth's axial precession and tilt changes and changes in its orbital eccentricity, are mainly associated with driving cyclic ice ages.
- The two known longer climate cycles, 32My and 141My, also drive the climate system through CRF changes and the cosmic ray/cloud/albedo link.

3.7.2 Calculating the minimum pressure-induced temperature

The temperature gradient associated with all Solar System bodies with thick atmospheres is caused by adiabatic auto-compression; it is also called the 'lapse rate' by meteorologists. On Earth, it affects the troposphere the most, because it mainly operates in pressures above 10 kPa. As noted in section 3.5 the dry lapse rate is 9.8K/km, and the official U.S. average lapse rate globally is 6.49K/km (Petty, 2008). However, the lapse rate is much lower where water vapour is involved, and falls to 3.5K/km in fully saturated air in the tropics. If the minimum possible atmospheric warming from adiabatic auto-compression could be known as a starting point, then a step forward will have been made. The formula for calculating the wet bulb lapse rate is as follows (M. J. McPherson, 2012);

$$\frac{\mathrm{dTw}}{\mathrm{dP}} = 0.286\ \frac{[(1+1.6078\ Xs)Tw/P+\frac{Lw\ Xs}{287.04\ (P-es)}]}{[1+1.7921\ Xs+(Lw^2P\ Xs/\ 463.81x\ 10^3(P-es)Tw^2)\ ]}\ \mathrm{°C/Pa} \qquad (16)$$

Where;

Tw	absolute wet bulb temperature
P	Pascals
dTw/dP	wet bulb lapse rate
Xs	kg/kg dry air
es	variable in kPa
Lw	Joules/kg
dP	variation in pressure

McPherson has already performed the necessary calculations and presents them in a convenient graph form; temperature change vs wet bulb temperature (Figure 3.84). This clarifies the rate of warming in the near-surface of the tropics, it would be ~3.5°C/km. Here would be a minimum warming figure globally for the effects of adiabatic auto-compression. The potential warming was calculated earlier, using the standard U.S. lapse rate of 6.49°C/km, to be ~32.5°C. In this case, the minimum warming rate is used, and the minimum height of the troposphere, (5km) to arrive at the lowest possible surface temperature enhancement from adiabatic auto-compression;

~5 x ~3.5 = ~17.5°C.

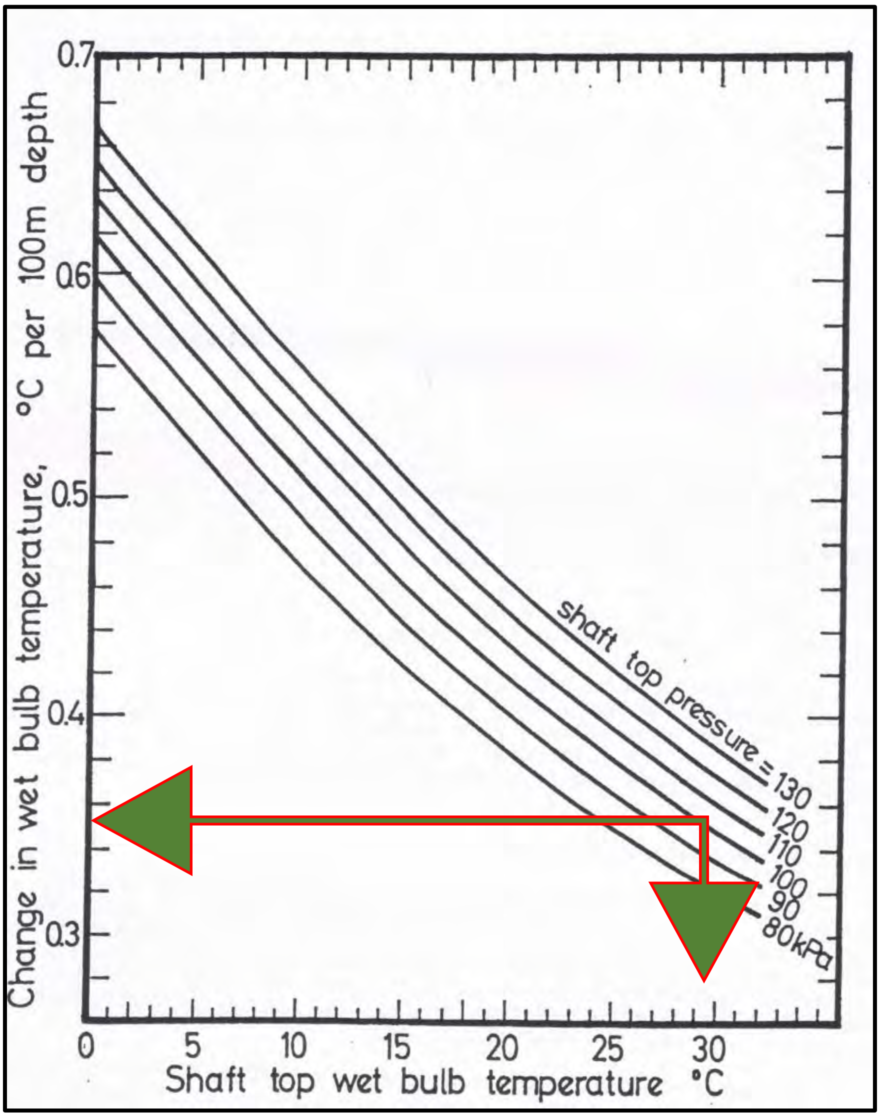


Figure 3.84 Adiabatic auto-compression in saturated air (M. J. McPherson, 2012)

3.7.3 Four parameters to calculate the temperature at planetary surfaces

The formula to be used is;

$$T_s = E_qT - (LR_{ave} \text{ x } (h_s - ERL)) \qquad (17)$$

Where;

T_s	temperature on the surface in °C
E_qT	planetary effective radiating temperature in °C
LR_{ave}	the average lapse rate in °C/km
ERL	the effective radiating level in km; (the height where surface pressure/2)
h_s	the height above or below surface that the temperature is desired for; in km

Here, the average temperature at the planetary surface is calculated for the three rocky bodies in the Solar System which have the thickest atmospheres; Venus, Earth and Titan. This is done with a simple formula, and very accurately, all are within a small; margin of the actual measured temperatures. As with the next calculations using the ideal gas law, no inclusion or adjustment is apparently needed for such parameters as insolation, albedo, atmospheric composition or greenhouse effect. Indeed, one more term (h_s) can in fact be excluded as well, further simplifying matters; this is only needed if an atmospheric temperature other than that at the surface is required. As an example, to obtain the average temperature in Earth's atmosphere at a height of 2km above sea level;

$$T_{2km} = -18 - (6.5 \times (2 - 5))$$
$$T_{2km} = +1.5°C$$

Earth suggested temperature at 2km = +1.5°C (274.7K)

The U.S. standard SI atmospheric air properties, lists 2km above sea level as being 275K.

Using the properties of Venus from Table 3.3;

$$T_s = +260 - (10 \times (0 - 20))$$
$$T_s = +460°C$$

Venus suggested surface temperature = +460°C (733K)

Using the properties of Earth from Wiki (Wikipedia, 2017)

$$T_s = -18 - (6.5 \times (0 - 5))$$
$$T_s = +14.5°C$$

Earth suggested surface temperature = +14.5°C (287.5K)

Using the properties of Titan as reported from the Huygens probe (Fulchignoni et al., 2005)

$$T_s = -191 - (0.9 \times (0 - 13))$$
$$T_s = -179.3°C$$

Titan suggested surface temperature = -179.3°C (93.7K)

3.7.4 Using the ideal gas law to calculate temperatures at planetary surfaces

It appears possible that the ideal gas law may be used to more accurately determine surface temperatures of planets with thick atmospheres than the S-B black body law, using just three gas parameters. To do this, an atmospheric density term, ρ is to be included, and since kg/ m³ is to be used for density instead of grams/ m³, the V term can be dropped.

The ideal gas law is;

$$PV = nRT \qquad (18)$$

Convert to temperature; $T = PV/nR$

Drop the V term; $T = P/(R.\rho/M) \qquad (19)$

Gas constant; 8.314

Where;

T 'surface' atmospheric temperature in Kelvin

P	'surface' pressure in kPa
V	volume in litres
n	number of moles
M	mean molar weight of the troposphere
R	gas constant for litres, Kelvin, moles and grams is 8.314
ρ	density of the atmosphere kg/ m³ at surface for rocky planets or at 101.3 kPa (1 atm) for the gas giants

Using the properties of Venus from Table 3.3;

$$T = \frac{9200}{(8.314 \text{ x} \frac{65}{43.45})}$$

Venus suggested surface temperature = 739.7K

Using the properties of Earth from Wiki (Wikipedia, 2017)

$$T = \frac{101.3}{(8.314 \text{ x} \frac{1.225}{28.97})}$$

Earth suggested surface temperature = 288K

Venus is calculated at 739.7K, which is given by NASA as ~740K; this is close. Earth is calculated at 288K, currently its quoted at 288K. This is more accurate than using any other method, and should work for all planets with atmospheres thicker than 10 kPa (0.1bar). Saturn's moon Titan will suffice as a further test. Unfortunately, no exact data on the surface density of Titan's atmosphere could be obtained, but it can be calculated from other known data from the Voyager 1 probe (Lindal et al., 1983), thus;

$$\begin{aligned} \rho &= MM.P/RT \qquad (20) \\ &= 27.4 \text{ x } 146.7/8.314 \text{ x } 93.7 \\ \rho &= 5.16 \text{ kg/ m}^3 \end{aligned}$$

It will be noted that the atmospheric temperature and pressure on the surface of Titan was inferred by the Voyager 1 probe, and measured by the Huygens lander probe (Fulchignoni et al., 2005) these are needed here as an input to find the surface density. The 93.7K will therefore come out of the below formula, since it is a rearrangement of formula 16. The lander also measured the temperature and height of the tropopause at 70K and 44km respectively.

$$T = \frac{146.7}{(8.314 \text{ x} \frac{5.161}{27.4})}$$

Titan suggested surface temperature = 93.7K

Calculate for Mars (NASA factsheet data);

$$T = \frac{0.6}{(8.314 \text{ x} \frac{0.020}{43.34})}$$

Mars suggested surface temperature = 156K

The average temperature on Mars is 218K; as suspected from other work (Robinson & Catling, 2014) this method is inaccurate for Mars, probably due to the very low atmospheric pressure. As mentioned, it is only in atmospheres with a pressure of over 10 kPa (0.1bar) that strong convection and a troposphere/tropopause is formed, and its associated temperature gradient via auto-compression. Now the gas giants will be assessed, using a pressure of 101.3 kPa as a 'surface'.

Calculate for Jupiter (NASA factsheet data);

$$T = \frac{101.3}{(8.314 \text{ x} \frac{0.160}{2.2})}$$

Jupiter suggested temperature at 1atm of pressure = 167K

The temperature on Jupiter at 1atm of pressure is 165K; the suggestion is very close.

Calculate for Saturn (NASA factsheet data);

$$T = \frac{101.3}{(8.314 \text{ x} \frac{0.190}{2.07})}$$

Saturn suggested temperature at 1atm of pressure = 132.8K

The temperature on Saturn at 1atm of pressure is 134K; the suggestion is very close.

Calculate for Uranus (NASA factsheet data);

$$T = \frac{101.3}{(8.314 \text{ x} \frac{0.420}{2.64})}$$

Uranus suggested temperature at 1atm of pressure = 76.6K

The temperature on Uranus at 1atm of pressure is 76K; the suggestion is almost exact.

Calculate for Neptune (NASA factsheet data);

$$T = \frac{101.3}{(8.314 \text{ x} \frac{0.450}{2.53})} \qquad T = \frac{101.3}{(8.314 \text{ x} \frac{0.450}{2.69})}$$

In the case of Neptune, NASA gave two mean molar weights; 2.53 and 2.69, this necessitated two separate calculations to give a high and a low of suggested temperatures.

Neptune suggested temperature at 1atm of pressure = 68.5K to 72.8K

The temperature on Neptune at 1atm of pressure is 72K; this lies between the two suggested temperatures.

Table 3.5 Comparison of ideal gas law calculated, and actual surface temperatures

Planetary body	Calculated temperature Kelvin	Actual temperature Kelvin	Error
Venus	739.7	740	0.04%
Earth	288	288	0.00%
Titan	93.7	93.7	0.00%
Mars	156	218	28.44%
Jupiter	167	165	1.20%
Saturn	132.8	134	0.89%
Uranus	76.6	76	0.79%
Neptune	68.5 to 72.8	72	0.00%

If this simple relationship between surface atmospheric density, pressure and molar mass proves to be an accurate method of predicting surface temperatures on bodies with a thick atmosphere, it will necessarily be informative about what actually determines these planetary surface temperatures.

3.7.4.1 Conclusion to the use of the ideal gas law for planetary atmospheres

It is apparent that this simple formula accurately calculates the 'surface' temperatures on planetary bodies in the Solar System, which have atmospheres thick enough to form a troposphere (i.e. over 10kPa or 0.1bar). This is done without using the S-B black body law, the greenhouse effect, albedo, or recourse to TOA TSI levels. Surprisingly, all that is required is three gas variables and one gas constant; the atmospheric surface pressure, atmospheric surface density, the average molar mass and the appropriate gas constant. That the average surface temperature of any planetary body with a thick atmosphere can be calculated accurately, and without recourse to any adjustment for a postulated or assumed greenhouse effect is telling. The implication is that since this formula, derived from the ideal gas law, can very accurately predict the average surface temperature of any planetary body with a thick atmosphere using only three gas parameters, the climate sensitivity to a doubling of CO_2 has to be very low. The actual change in atmospheric temperature due to a doubling of CO_2 would be so low that it would be impossible to measure in the real atmosphere; a calculation suggests it is below +0.12°C.

A *reasonable expectation* would be that a 0.04% increase in atmospheric CO_2, which is a relatively heavy gas, could be expected to result in the following approximate atmospheric changes in the three gas parameters;

Pressure:	an increase of 0.04%
Density:	an increase of 0.05%
Molar Mass:	an increase of 0.05%

Calculate using formula 19, a doubling of CO_2 from the current level of 0.04%;

$$T = \frac{101.34}{(8.314 \text{ x} \frac{1.2256}{28.984})}$$

Calculated temperature after doubling of CO_2 to 0.08% ≈ 288.25K

'Reasonable Expectation' equilibrium climate sensitivity to CO_2 ≈ 288.25 - 288.14 ≈ +0.11K

Looking at the suggested temperatures for the planetary bodies, they are so accurate (all spot on except for Mars, which is has a very thin atmosphere) that it is possible one or more of the parameters were originally calculated and not measured. Nevertheless, even if some of the temperatures were calculated and not measured, the relationship existing between the numbers is still quite interesting and remarkable; the calculated values are unlikely to be very dissimilar to the actual values when they are measured.

Perhaps a key point here is that our atmosphere is retained by gravity but is nevertheless unbounded and is made of gases. Gases obey thermodynamic and gas laws. A gas which is unbounded and subjected to a positive forcing causing warming will expand; in expanding, the gas will cool again. If an atmosphere expands due to a warming forcing, kinetic energy will be converted to potential energy, resulting in little if any residual warming.

3.7.4.2 Conclusion to the use of novel ways to calcuate temperatures

The discovery of these novel, yet very accurate and very simple methods of calculating the surface temperatures of planetary bodies with thick atmospheres, seems to be instructive about what really contributes to the construction of a surface atmospheric temperature. The information contained in, or intrinsic to these individual parameters forms a large part of the contribution. For example, take just the simple density parameter, ρ. This one number contains information about the height of the column of gaseous substance which is held to the planetary body by gravity; and information about the strength of the force of gravity at the surface of the body, which in turn, relies on the relationship between the mass and the diameter of the body.

3.7.4.3 The Eocene thermal maximum – why was it so hot?

If this line of thought is taken one step further, a relatively recent high in the Earth's global temperature record was the Eocene thermal maximum, at ~50Mya (Figure 3.29). It is known from different proxy records (Zeebe, Zachos, & Dickens, 2009) that this warm period covered the 48Mya – 56Mya period, and it was at least 8K warmer than it is today. What could cause such a large and long period of warming? Bearing in mind the gas calculations just made, there remains a possibility that the Earth's atmosphere was much thicker then, for example due to strong out-gassing from tectonic changes. If the hypothesis is that this extra gas resulted in an atmospheric surface pressure of 172 kPa and then in a near-surface density of 2.1kg/ m³ and that more atmospheric oxygen raised the average molar mass to 30, then the following gas law calculation is arrived at;

$$T = \frac{172}{(8.314 \times \frac{2.1}{30})}$$

An early Eocene suggested surface temperature of = ~296K (23°C - the 'hothouse' Earth)

Of course, currently this is speculation, and these numbers were chosen specifically to provide this temperature – and assumes that auto-compression was responsible for the 8K rise. Although the actual atmospheric properties from 50Mya are not currently known, this example could provide a viable predictive test of this hypothesis – and if confirmed, a valuable predictive tool of atmospheric conditions in different eras.

3.7.5 Using just two parameters to calculate the temperature of planets

Two physicists have published a paper where they say that the surface temperature of planetary bodies with thick atmospheres can be calculated accurately by the use of only two parameters (Principles et al., 2011) - these are the TOA insolation and the surface atmospheric pressure. In that work, Nikolov and Zeller have introduced the term 'near-surface thermal enhancement' (NTE) in order to distinguish their causes of the surface warming phenomena known to be associated with the presence of an atmosphere, from radiative greenhouse warming. NTE is defined as the ratio between the actual average atmospheric surface temperature and that calculated using the S-B grey body law.

Their derived formula is as follows;

$$Ts = 25.3966\ (So + 0.0001325)^{0.25}\ NTE\ (Ps) \qquad (21)$$

Where;

Ts	is the average surface atmospheric temperature in Kelvin
So	is the TOA insolation in W/m²
NTE	is the ratio of surface temperature to S-B grey body temperature
Ps	is the near-surface atmospheric pressure

Since it is probable from the last section, that the ideal gas law can be used to accurately calculate this very same average surface temperature, using just three gas parameters – one of which is the surface atmospheric pressure – they are therefore inferring that TOA insolation is somehow related to a combination of surface gas density and the tropospheric mean molar weight. The mechanism for such a relationship is not immediately apparent, and if it exists its discovery will be left to others.

Nevertheless, the paper contains interesting speculation on the causes of temperature changes on Earth during the Cenozoic Era, suggesting that over these longer periods of time, a large cause of what determines the surface temperature on Earth is the atmospheric density. This has also been suggested by others (J. Kiehl & Dickinson, 1987) (L. F. Khilyuk & Chilingar, 2006) (Sorokhtin et al., 2007) (Gerlich & Tscheuschner, 2010).

3.7.6 What causes the surface gas temperature on planetary bodies?

It is easily seen that the science is far from settled on even the most basic questions in climate science, such as what are the main factors that cause a certain surface atmospheric temperature to emerge on a planetary body with a thick atmosphere.

3.8 Climate controversies

3.8.1 The hockey stick curve

The 'hockey stick' curve or graph (Figure 3.7) (Mann et al., 1998) quickly became contentious because of its flat representation of almost the entire reconstructed temperature record, covering 1000AD to 2000AD. And then in the late 20th century, in the 'blade' of the hockey stick, temperatures suddenly rose dramatically, in line with the known growth in anthropogenic emissions of GHG. The reason for the doubts about the accuracy of the graph is because it appeared to dismiss the existence of several known and well-documented historical climatic changes, including the warming around 1400 and the LIA cooling which occurred around 1700. A counter-paper was published (McIntyre & McKitrick, 2004) several years later, which said it had found fundamental flaws in the algorithm used, such that it always created a hockey stick shaped graph from any inputted data; even random noise. The correction to the hockey stick graph's problems in this paper, showed that temperatures around 1400 were actually 0.5°C higher than shown in the hockey stick, a temperature which aligns much better with written historical records and other proxy reconstructions from the period.

The hockey stick was created from tree ring proxies, a proxy record for temperatures which is known to have problems (Loehle, 2007). The hockey stick seemed to completely erase the MWP and the LIA, both of which were very prominent in a temperature reconstruction that was used in the first IPCC assessment report. Four more recent Northern Hemisphere reconstructions, which cover the last 2ky, show a more accurate level of natural variability (top of Figure 3.85).

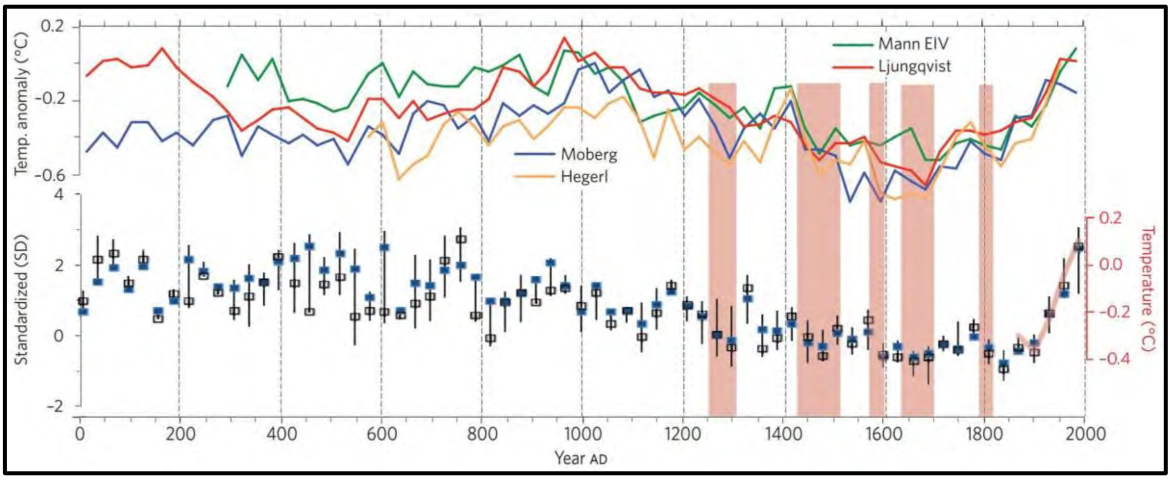


Figure 3.85 Proxy trends vs a seven-continent reconstruction (Ahmed et al., 2013)

For comparison, a 30-year mean average is shown (bottom of Figure 3.80), which comes from proxies in all seven continents (Ahmed et al., 2013) and which shows a general decline in temperatures until ~1820. This reconstruction is thus a little different to many others, which generally show that the coldest part of the last 2ky was definitely in the late 1600's. Of note however, is that six of the 20 individual proxies used in this seven-continent reconstruction were from tree rings.

Another difficulty with the hockey stick, that is hardly ever mentioned, is that it was not a global reconstruction; it covers only the Northern Hemisphere, and it only went back 600 years. Other reconstructions cover a longer period, 2ky, (Figure 3.86) are from non-tree proxies, and have sources that are spaced globally in nature (Loehle, 2007). The non-tree ring proxies generally show a much greater temperature variation; (~1.2°C of cooling from MWP to LIA) which do accord better with known and recorded historical climate changes, both in Europe and in China. Compare Figure 3.86 to Figure 3.85.

The hockey stick graph received bad press, but this should not mean that proxy tree-ring results from other researchers should be completely disregarded, because some of these have provided useful data. For example, a Mongolian tree-ring study covering the last 450 years has shown a reasonable variability, which is in line with other proxies (Jacoby, Arrigo, & Davaajamts, 1996). It has also shown that the strongest warming period in the last 450 years was the 1850 – 1950 period, with little subsequent warming after 1950. Recently, the same researchers extended their study to cover 1,738 years (D'Arrigo et al., 2001) that revealed a severe cooling around the year 540, which seems consistent with other proxy records.

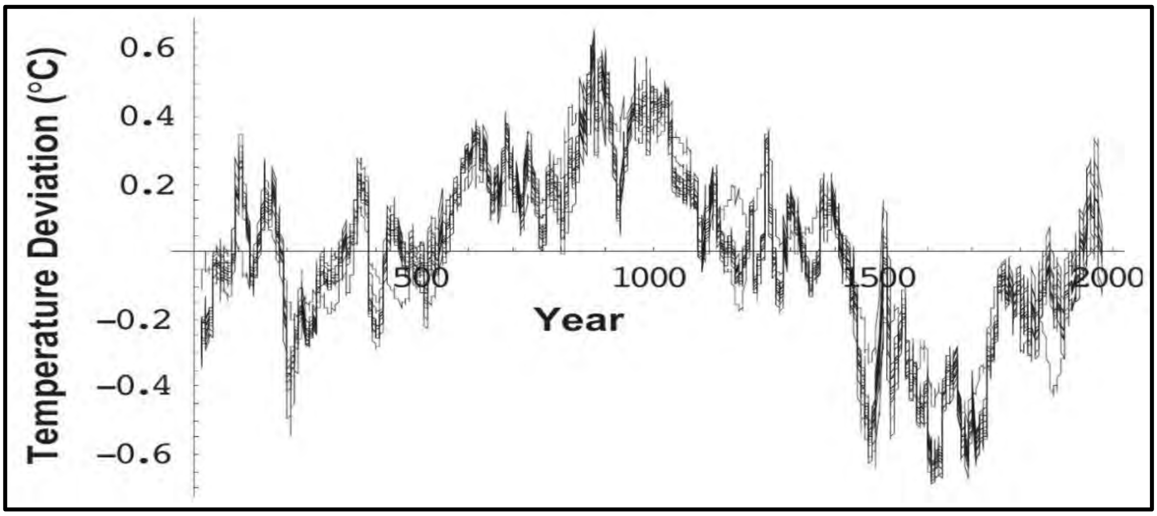


Figure 3.86 A 2000-year compilation of 18 non-tree ring proxies (Loehle, 2007)

3.8.2 Climategate emails

Shortly before the 2009 COP 15 meeting in Copenhagen, an anonymous whistle-blower leaked thousands of emails which involved the planet's top climate scientists who work out of the UK's climate research unit and Hadley centre, the Penn state university in the USA and others. The emails revealed that group-think existed within the small number of very active scientists in the field of climate, as shown earlier (Wegman, 2006). More worryingly, they showed collusion in the peer-review process to keep papers sceptical of their hypothesis from being published in any of the prestigious climate journals. Other problems were data manipulation, a refusal to release data or methods for the verification of work, the refusals persisted even under FOI requests (Leiserowitz, Maibach, Roser-Renouf, Smith, & Dawson, 2013). These revelations did nothing to endear an already sceptical public to climate science and its climate scientists, and this has been reflected in polls (Have your say, 2015). Many say that traditional science in this field has been left behind, and a new era has begun, one consisting of what has been termed 'post-normal science', (Ravetz, 2011) this is where precaution and consensus takes precedence over scientific evidence when formulating action.

3.8.3 NOAA's Karl et. al. paper

In an incident that some are calling climategate II, a scandal presently surrounds the publication of a NOAA paper in the northern summer months of 2015, just before 190 nations met at COP21 in Paris to discuss possible climate action. This paper (Karl et al., 2015) discredited the existence of the 20-year 'pause' or 'hiatus' that heretofore was seen in all global near-surface temperature datasets. The global temperature 'pause' was the subject of much discussion at climate conferences – and several papers were published in attempts to explain it; it was also mentioned in the IPCC's AR5. The Karl work was released at a key time, and could have been instrumental in decision-making at COP21.

The Karl et. al. study was subsequently exposed in February 2017 by whistle-blower climate scientist Dr John Bates, who is a respected recently-retired scientist from NOAA. Bates has had a 40-year career in meteorology and climate science, including the last 14 years at NOAA's national climatic data centre as principal scientist, from where the Karl paper originated. Bates has presented evidence in an interview to the U.K. media (Daily Mail, 2017) that the Karl et. al. paper was based on quote; *"unverified"* data and was quote; *"a blatant attempt to intensify the impact"* on politicians that the so-called 'pause' or 'hiatus' did not exist by publishing this paper just months before the signing of the Paris climate agreement in December 2015. In the Daily Mail interview, Dr Bates said;

> *"They had good data from buoys. And they threw it out and 'corrected' it by using the bad data from ships. You never change good data to agree with bad, but that's what they did – so as to make it look as if the sea was warmer." (Daily Mail, 2017)*

Dr Bates was also concerned that NOAA's procedures were not followed during the study and that none of the raw data was archived; a further problem was that much of the data used in the study was lost later in a 'computer failure', making it impossible to verify their results. An on-going investigation into NOAA's climate practices by the U.S. House committee responsible for oversight; the committee on science, space & technology (U.S. House, 2017) was expanded in early 2017 to include the Karl scandal. NOAA has so far refused to comply with a congressional subpoena from that oversight body, asking for data, information and emails relating to the Karl et. al. study. The publication of this study raises questions not just about the practices at NOAA, but about the peer-review process in the field of climate. This paper was published very rapidly and apparently without a problem in one of the most prestigious scientific journals on the planet, *(Science*) even though the highly contentious nature of the paper's content must have been known to the reviewers.

3.8.4 Sea level rise

One of the main fears which arise from the projections of the CO_2-driven global circulation models is that of sea level rise. Hundreds of millions of people live near the coasts, and many of these live close to sea level. A relatively sudden rise in sea levels of say 100cm by 2100 would mean the re-location of tens of millions of people, and the possible loss of some low-lying Pacific island chains. NOAA's 2012 report on sea levels for the United States (Sweet et al., 2012) predicted a best-case scenario of 30cm and a worst-case scenario of 200cm by 2100 (this has been increased to 250cm in their newly-released 2017 report) (Horton, Rahmstorf, Engelhart, & Kemp, 2014). However, in the detail of the report, NOAA say that even in the worst-case climate scenario from the IPCC in AR5, the RCP8.5, the sea level rise still has a 96% chance of staying below 50cm, and only a 0.1% chance of reaching 250cm by 2100.

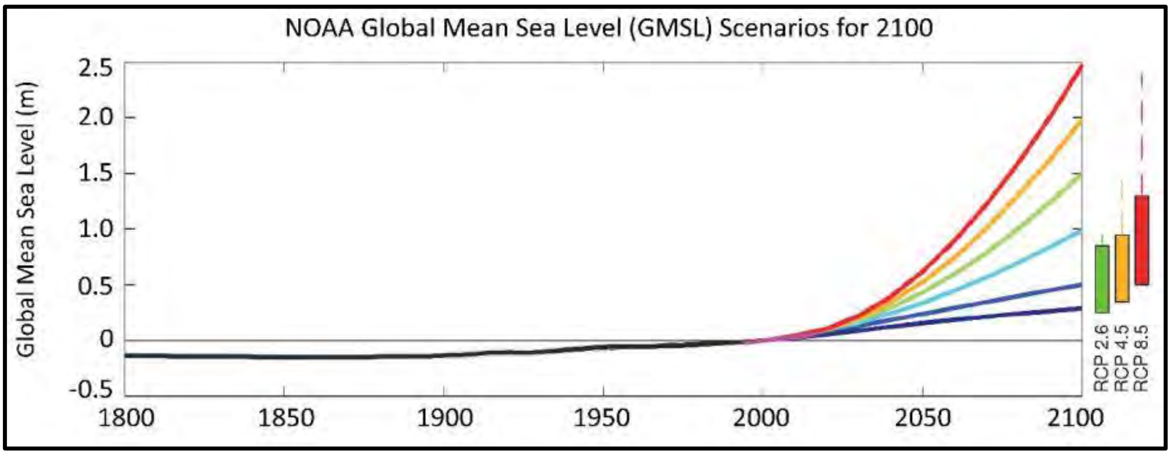


Figure 3.87 NOAA 2100 projections (Horton, Rahmstorf, Engelhart, & Kemp, 2014)

The graph they provide (Figure 3.87) may well be seen as misleading, since it appears that each coloured sea level rise scenario is the projection for each RCP, when in fact these lines represent only the very worst-case scenario from each projection, which has an extremely low probability of occurrence of only one-in-a-thousand. In fact, the RCP8.5 scenario itself already has a very low probability of occurrence, not least because a large positive feedback – leading to a high climate sensitivity, would greatly over-predict measured past global warming, and so is hardly possible (Charney et al., 1979).

Sea levels have been rising for hundreds of years, but at a slow rate; the general agreement among scientists is that sea levels rose just 17cm in the 20th century (Church &

White, 2011). However, the AR5 projects 28cm – 98cm of rise in the 21st century (Team et al., 2014) based on climate model scenarios. Some of this projected rise is related to ocean expansion due to warming, some due to land ice melt; both contributors fully depend on a temperature rise near the high end of the predicted range, to get to a total sea level rise of near 98cm by 2100. But, as mentioned, the Antarctic has not been warming in the last 50 years, thus far defying all modelling projections. Similarly, measured global temperatures to date have remained lower than almost all climate model projections (Figure 3.93).

Since the Antarctic is where ~90% of the planet's land ice is located, unless conditions there change dramatically, it is hard to see how the land ice melt component could be sufficient to cause a total of ~1m in sea level rise by 2100. According to some research papers (Zwally et al., 2015), measurements show that neither the land ice nor the sea ice of Antarctica is melting; rather, they are both growing. Greenland too, does not appear to be losing ice, on an overall mass balance basis, since 1866 (Wake et al., 2009). Under the A1b scenario (Team et al., 2014) which projects a balanced use of energy sources through to 2100, modelling has found that Antarctica alone could contribute (Ritz et al., 2015) up to 30cm to sea levels by 2100. But estimates of the contribution to the recent sea level rise 2003-2010 from all melting landed ice, totals just 1.48mm ± 0.26mm yr^{-1} (Jacob, Wahr, Pfeffer, & Swenson, 2012), if extrapolated out to the year 2100, this source adds just 12cm to sea level rise.

The pre-eminent authority globally on sea level rise is undoubtedly the international union for quaternary research (INQUA). And if a person were to be nominated, who is probably the greatest living authority on sea levels, it would be Professor Nils Axel Mőrner; INQUA's president 1981-89. Mőrner has published hundreds of papers in the last 45 years in the scientific literature, and wrote many books since 1971 on coastal morphology, isostatic, eustatic and other factors affecting ocean levels. Mőrner's view is that a sea level rise of over 50cm by 2100 is *"Absolutely impossible";* and the likely range of sea level change by that date will be +10cm, ±10cm relative to today. In other words, a minimum rise of 0cm, and a maximum rise of +20cm (N.-A. Mörner, 2004). The debate in the literature is not only about the level of contributions from the two main sources, ice melt and thermal ocean expansion, but is also about whether the rate of sea level rise itself is accelerating in response to an anthropogenic stimulus, which is a key point. Generally, proponents of the enhanced CO_2 hypothesis find a recent acceleration, and proponents of the null hypothesis find a deceleration, or no change in their published papers. However, in the AR5, they find that the sea level rise over the last two decades was no faster than that rate of rise in the 1930-1950 period (Figure 3.88), and a 1950-1980 slow-down (Team et al., 2014) also matches the global land surface changes seen in Figure 3.18. Again, oceanic thermosteric changes like these would tie-in well with, and correlates with the well-known 61-year Yoshimura climatic warming/cooling cycle.

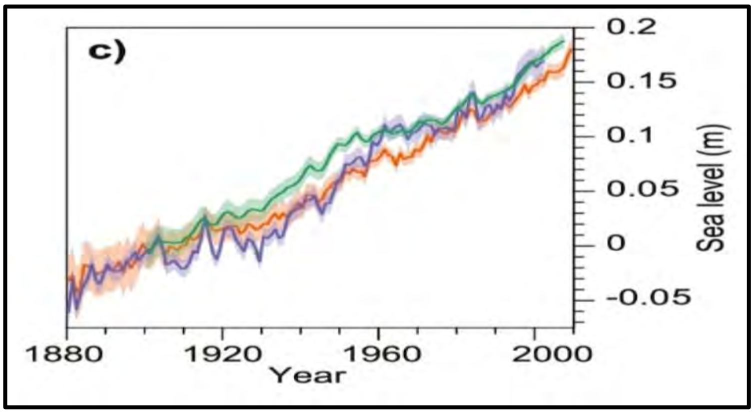


Figure 3.88 No unusual sea level acceleration is seen in AR5 (Team et al., 2014)

Note that the data which does show an acceleration during the last ~50 years) in Figure 3.88 comes from satellite data (Cabanes, Cazenave, & Le Provost, 2001). This has been spliced onto tide gauge data. However, the acceleration would not be unusual even if accurate since a similar acceleration is seen in the 1920-1950 period. The satellite method of measuring slow and minute changes in ocean levels, compares ranged distances to the ocean surface against a theoretical geoid of the Earth, from an orbiting satellite 200km up travelling at 27,000km/hr in a decaying orbit. Results obtained under these circumstances, need to be approached with a fair amount of scepticism.

Surely a more accurate method of obtaining data on sea level change, is directly from the planet's long-established system of tide gauges, but these are not used by the IPCC; satellite data is preferred instead. A global system of tide gauges has been in use for over a century, and researchers using this data find a sea level rise of approximately 1.3mm/yr, and also that this rate of rise is decelerating (Wöppelmann, Miguez, Bouin, & Altamimi, 2007) (Beenstock et. al., 2015). Other researchers also find a 20th century deceleration in rates of sea level rise, from an average of 2.03mm/yr (1904-1953) to 1.42mm/yr (1954-2003) (Holgate, 2007) (Figure 3.89). Low-lying Pacific and Indian island chains (N. A. Mörner, 2004) have also been surveyed; again, no acceleration in sea levels is seen, nor any concerning rise in sea levels; in fact, three times more islands in the Pacific were measured to be growing rather than shrinking (Webb & Kench, 2010).

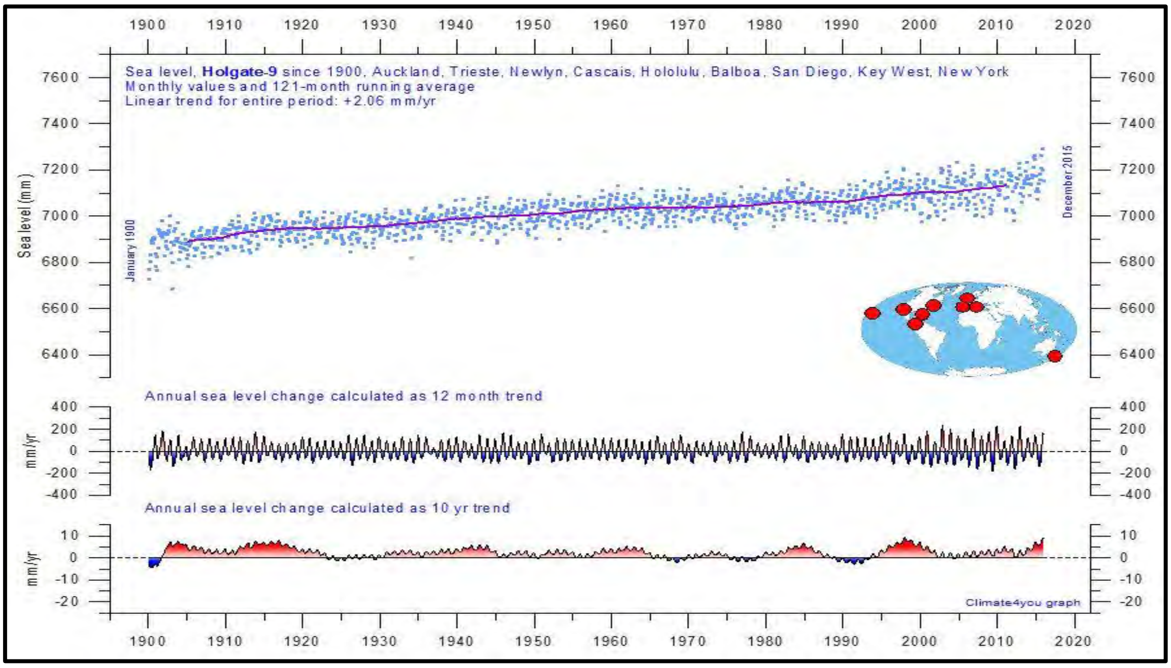


Figure 3.89 Average of 9 tide gauges since 1900 show a deceleration (Holgate, 2007)

3.8.5 Global ocean temperatures since 1900

On decadal time-scales, ocean temperatures are what really determines atmospheric temperatures; they are very closely linked. Oceans have an enormous moderating influence on the climate and they are where the heat content is; the oceans can absorb 1,000 times more heat than the atmosphere, and have absorbed (Solomon, 2007) 20 times more, just since 1960.

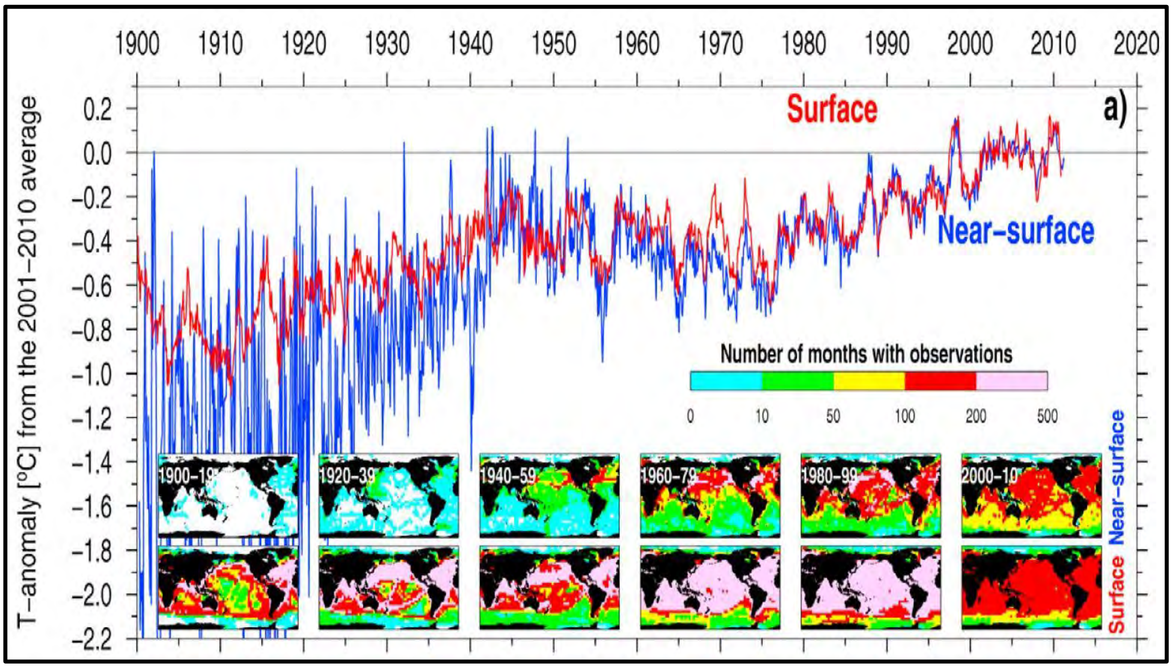


Figure 3.90 Ocean temperatures since 1900 (Gouretski, Kennedy, Boyer, & Köhl, 2012)

Several different historical global time-series of ocean surface and near-surface temperature records since 1900 have been compiled and compared (Figure 3.90) (Gouretski et al., 2012). What they show is a fall until 1910, then a very strong rise in global temperatures occurred 1910-1940, then a slow fall until 1975, then another rise until 1997, after which the record is flat; this is fully consistent with all credible atmospheric data. Unfortunately, this time series does not show the well-known 1880 peak, which, if the data were to be extended back that far, would show that the 1880, 1941 and 2002 peaks were close to one another both in temperature level, and in the temperature differences between them. This ~61 year spacing in oceanic temperatures is yet more confirmation of this very strong climate cycle. Any obvious influence from the rapid rise in atmospheric GHG during the late 20th century, is not seen in this data.

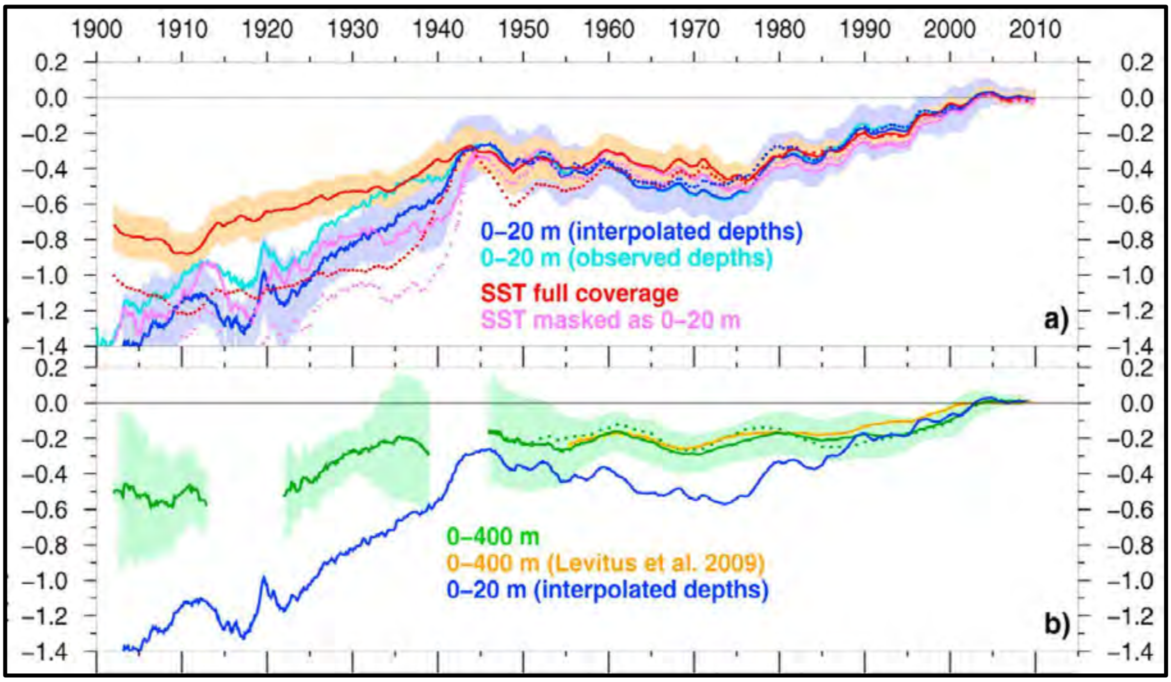


Figure 3.91 Global ocean temperature anomalies (Gouretski et al., 2012)

The same authors provide further information (Figure 3.91) in the form of 5-year running mean anomalies of 0-20m ocean temperature profiles; the lower figure (green line) includes deeper data from 0-400m, which shows less change than the 0-20m (blue line) and surface data. The recent pause or hiatus in oceanic temperatures is also clear.

3.8.6 What is the 'pause' or 'hiatus' and does it exist?

3.8.6.1 The slowing rate of global warming

Like the slowing rate of sea level rise, the rate of global warming has also slowed. According to the best data from NASA's TRIOS-N satellite (RSS MSU), the current level of temperature growth has slowed substantially, and over the last 20 years, is just 0.05°C/decade, which converts to an un-alarming 0.5°C/century (Figure 3.92). This trend, if projected to 2100, will add 0.4°C to current global surface temperatures. This figure is far below the COP21 target of 2°C above pre-industrial, (or 1.2°C above current temperatures).

A sceptic might point out that not one of the climate models predicted what has been called the 'pause' or the 'hiatus'. This is the slow-down in global warming which has happened since 1998, (Figure 3.93) despite the yearly increase in human emissions of GHG during this period; the fact is that more than 30% of the entire tonnage of CO_2 ever emitted

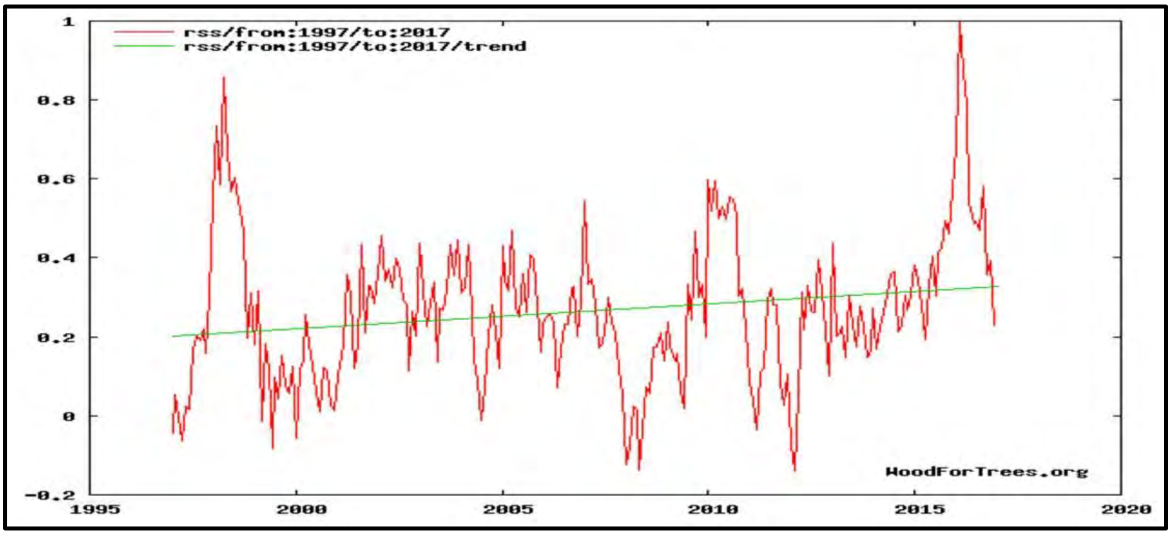


Figure 3.92 RSS MSU lower troposphere, with trend, 1997-2017 (Woodfortrees, 2017)

by humanity, was emitted during these few recent years, and atmospheric CO_2 levels have continued to rise. The EGGWH states that a rise in atmospheric CO_2 causes a commensurate rise in global surface temperatures; this is one of the main tests of the hypothesis, if there is no reaction in temperatures – the hypothesis is invalidated and must be discarded. The 'pause' or 'hiatus' has been acknowledged in the IPCC's AR5;

"The rate of warming over the past 15 years (1998–2012) is 0.05 [–0.05 to +0.15] °C per decade, which is smaller than the rate calculated since 1951 of 0.12 [0.08 to 0.14] °C per decade." (Team et al., 2014)

The EGGWH and the global circulation models actually projected the opposite - that given the higher CO_2 emissions, and the rising atmospheric CO_2 concentrations, warming must accelerate; instead, the rate of warming (and the rate of sea level rise) has decelerated.

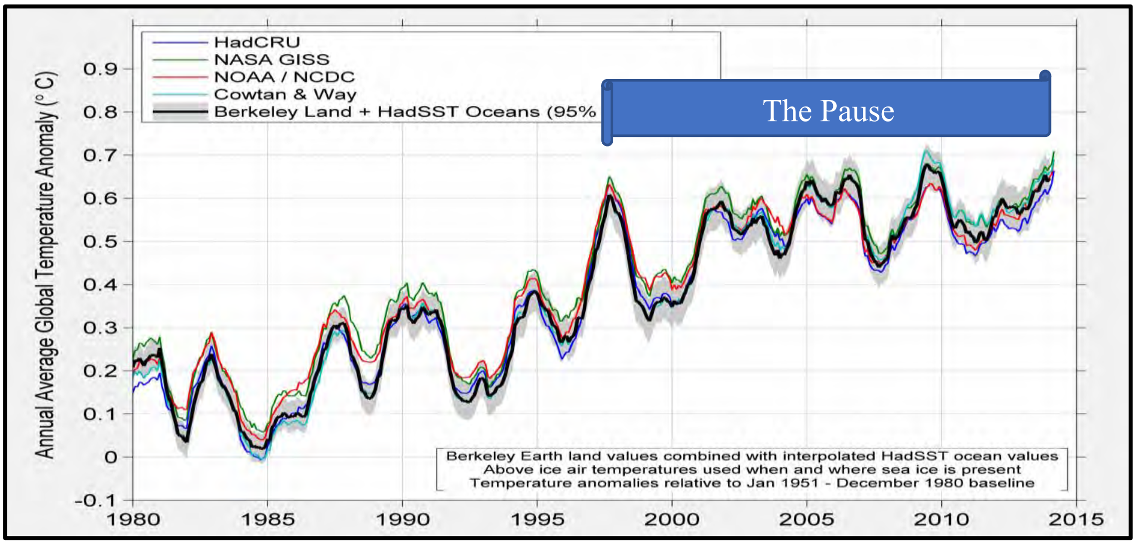


Figure 3.93 Five surface global datasets combined show the 'pause' (Okulaer, 2017)

This situation has led many mainstream climate scientists to look for the 'heat' that they say must have come from the extra GHG. Many papers have been published in the literature to try to explain where the so-called 'missing heat' went to (Hawkins, Edwards, & McNeall, 2014) (Kosaka & Xie, 2013) (Tollefson, 2014). It was finally determined, that it had been sequestered deep in the oceans by wind-driven currents (England et al., 2014); and then at last, that actually, there was no missing heat anyway (Karl et al., 2015).

A recent paper in nature (Santer et al., 2017) by some of the most prominent proponents of the EGGWH has gone some way towards acknowledging the pause, and that the model projections were wrong because they did not take account of natural variability.

3.8.7 Global circulation models; how useful are they for prediction?

Temperatures are currently in the lower 5% of the projections of the global circulation models (Figure 3.94), and are in danger of dropping out of the *likely* range altogether. In response to this failure of projections, a new, lower *likely* range for the 2016-2035 mean anomaly has been set in the latest IPCC report, at just 0.5°C (Team et al., 2014).

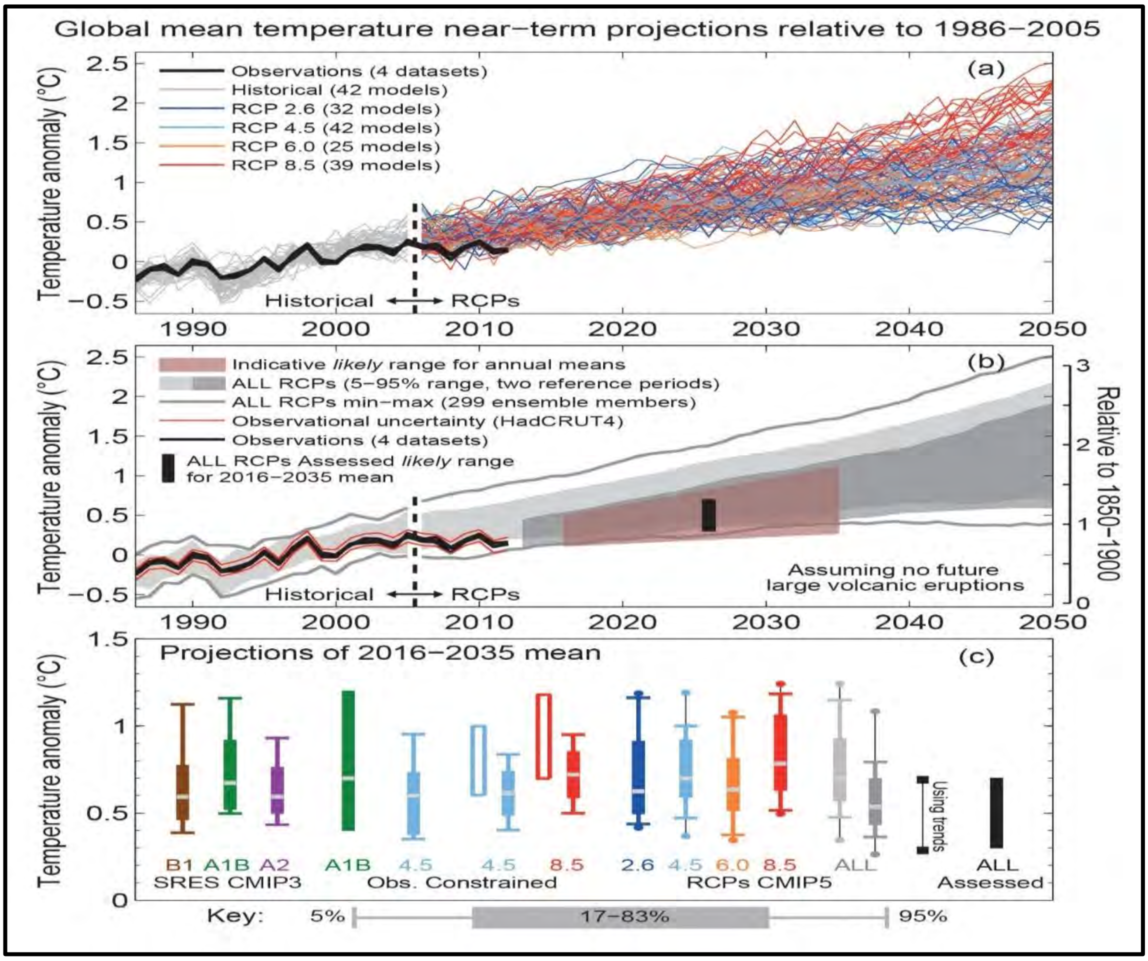


Figure 3.94 Real temperatures are now in the low 5% of projections (Team et al., 2014)

The models used by the IPCC are very poor at modelling natural variability such as volcanos and cloud changes; they also lack input from any of the known multi-decadal climate cycles. Instead, they are formulated so that an incremental increase in atmospheric CO_2 results in an incremental increase in global surface temperatures (Figure 3.94). One problem with this approach is that the overlap between CO_2 absorption and H_2O absorption is not correctly accounted for (Freidenreich & Ramaswamy, 1993).

Climatologist John Christy has compiled a simple comparison chart comparing the average projections of 102 climate models for the post-1995 period with the subsequent data from an average of 4 lower troposphere balloon datasets (in blue circles) and an average of the two lower troposphere satellite datasets (in green squares) to 2015 (Figure 3.95). The discrepancy between the model's projections and the reality, is already 0.6°C and is growing. When matched in the anomaly basis years, (1961-1990) the UK's MET office's forecast and hind cast of the 1900-2040 period using their CMIP5 climate model in the RCP4.5 mode, reveals a very poor correlation (Figure 3.95). And the UK's MET office forecasts have proven to be no better.

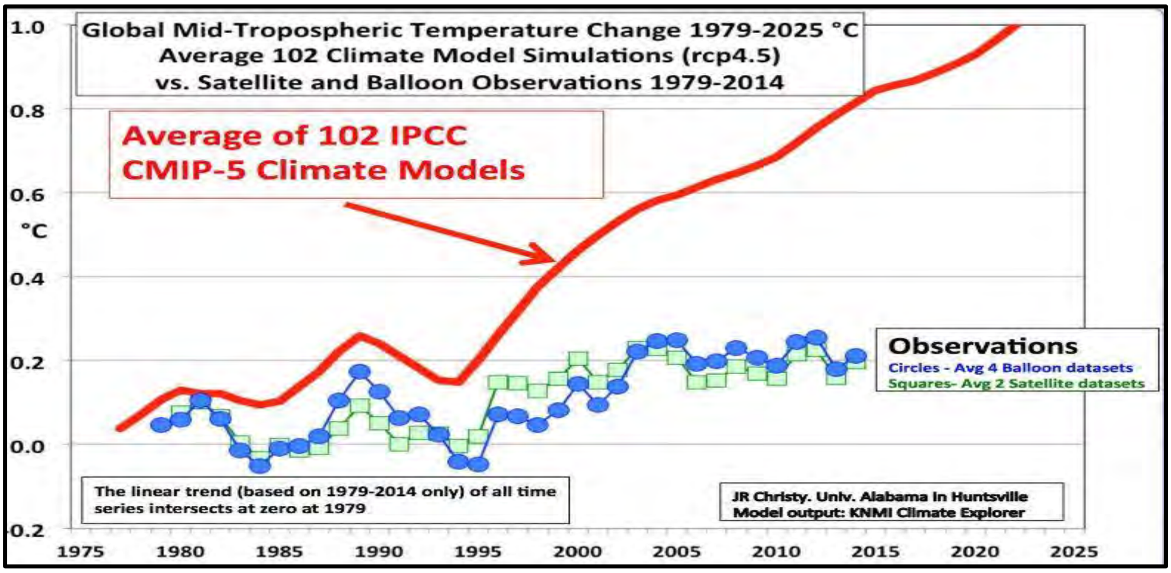


Figure 3.95 Climatologist John Christy's compiled comparison chart (Easterbrook, 2016)

The actual global surface temperature anomaly from the HadCRUT4 data is shown in black (Figure 3.96), with a MET office 4-year projection shown in blue on the end. It is apparent from this red curve that the MET office has not inputted any known climate cycles into this model, instead relying, as other modellers have, on what they think caused the 1945-1975 cooling trend – aerosols; this appears to be nothing more than a fudge factor.

As will be shown later, that cooling period is unlikely to have been caused by aerosols, and these probably had and have much less effect on global temperatures than has been attributed to them by climate modellers or the IPCC reports. The large negative forcing's commonly attributed to aerosols (Figure 3.6) for decades by EGGWH proponents, are also coming under considerable scrutiny in the literature (Stevens, 2015). The fact is that if less negative forcing comes from aerosols, then a commensurate lowering of GHG forcing is required – resulting in a lower climate sensitivity.

The very poor match between the latest CMIP5 climate model forecast and the subsequent temperature record has caused some independent climate researchers to create their own simple climate models; often with a far greater success at matching the record. For example, a correlation of 0.89 compared to the UK's weather forecaster, the MET office's CMIP5 model's poor correlation of 0.16 when modelling R2 (Irvine, 2014).

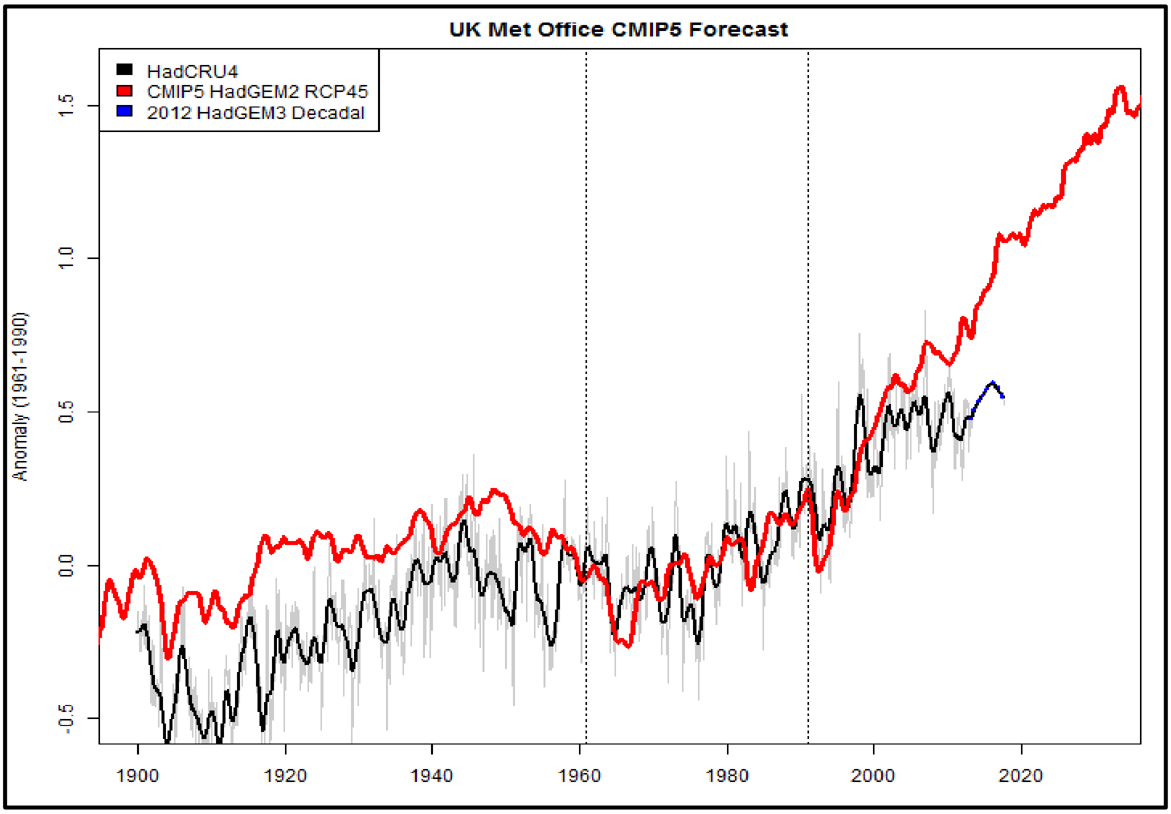


Figure 3.96 MET office CMIP5 model (red) vs HadCRUT4 (Climate Audit, 2013)

Irvine's model has produced a far lower climate sensitivity for ECS than the lowest estimates in the IPCC reports; as have other independently-produced models (Cederlöf, 2014) (D. Archibald, 2009) (Easterbrook, 2016) (Kissin, 2015) (Monckton et al., 2015).

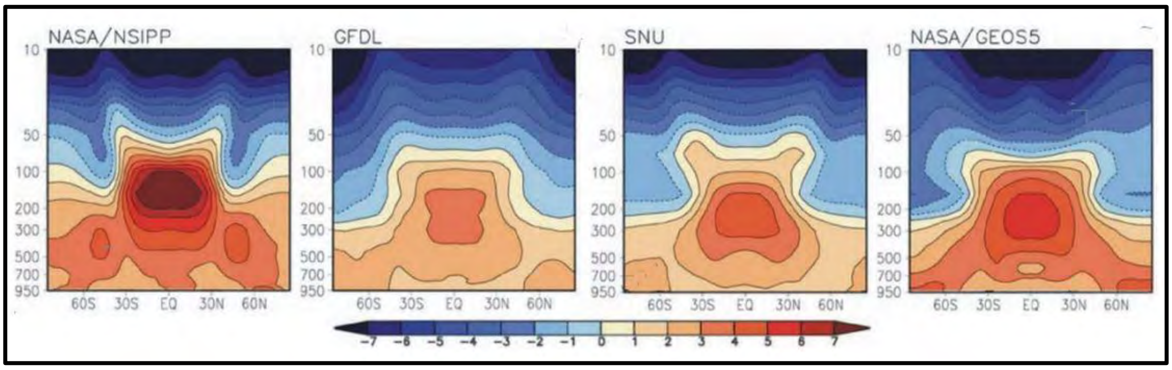


Figure 3.97 EGGWH predicts a hot spot will develop 9-12km up over the tropics

3.8.8 The tropospheric hot spot predicted by EGGWH is not detected

Figure 3.97 is four different modelled scenarios of a doubled atmospheric CO_2 concentration (M.-I. Lee, Suarez, Kang, Held, & Kim, 2008). The changes in the troposphere are in degrees centigrade, and the hot spot is predicted to occur at a pressure of 100 hPa - 300 hPa between the latitudes of 30°N and 30°S. The emission layer should be where the infra-red optical depth is near 1; this layer is just below the tropopause (Lindzen,

2007) and GHG theory says warming should be 2-3 times what is experienced near the surface. This is the signature of greenhouse warming that should be looked for in tropospheric temperature data, another part of the signature is that both polar regions should warm together; however, none of this is seen in the actual data (Singer, 2011) (Figure 3.98).

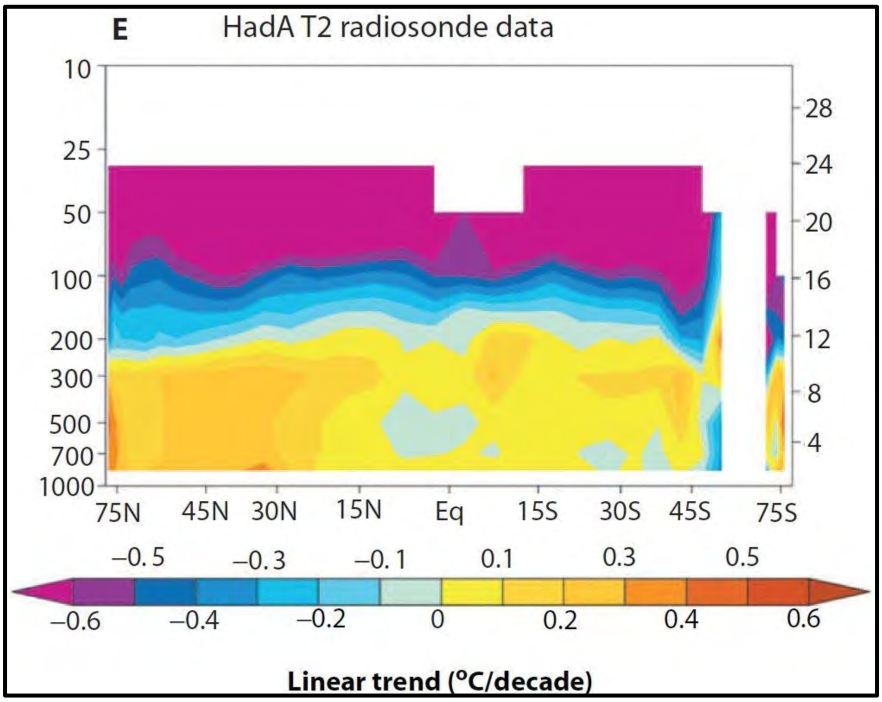


Figure 3.98 Radiosonde data 1979-1999 fails to detect a hot-spot (Singer, 2011)

A great scientist, Richard Feynman, wrote in science books to beware of fooling yourself; and he reminded his students in a famous lecture, about using the scientific method, and the one simple, basic test which must be applied to any hypothesis or model;

"If it disagrees with the evidence - it's wrong." (Feynman, 1974)

NASA's TRIOS-N satellite has provided data to remote sensing systems (RSS-MSU) where it was compiled by by Dr Carl Mears, and the resultant trend shows no warming at the key 10km height over the tropics in the 1987-2015 period (Figure 3.99).

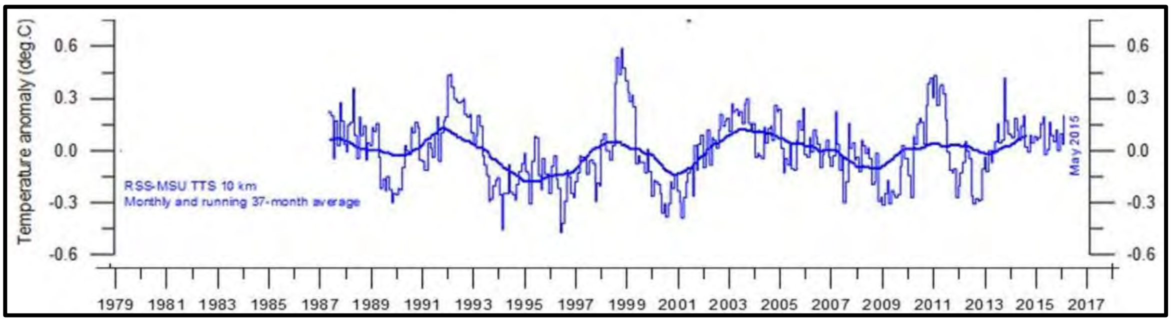


Figure 3.99 RSS-MSU data 1987-2015 shows no warming at 10km (Climate4you, RSS)

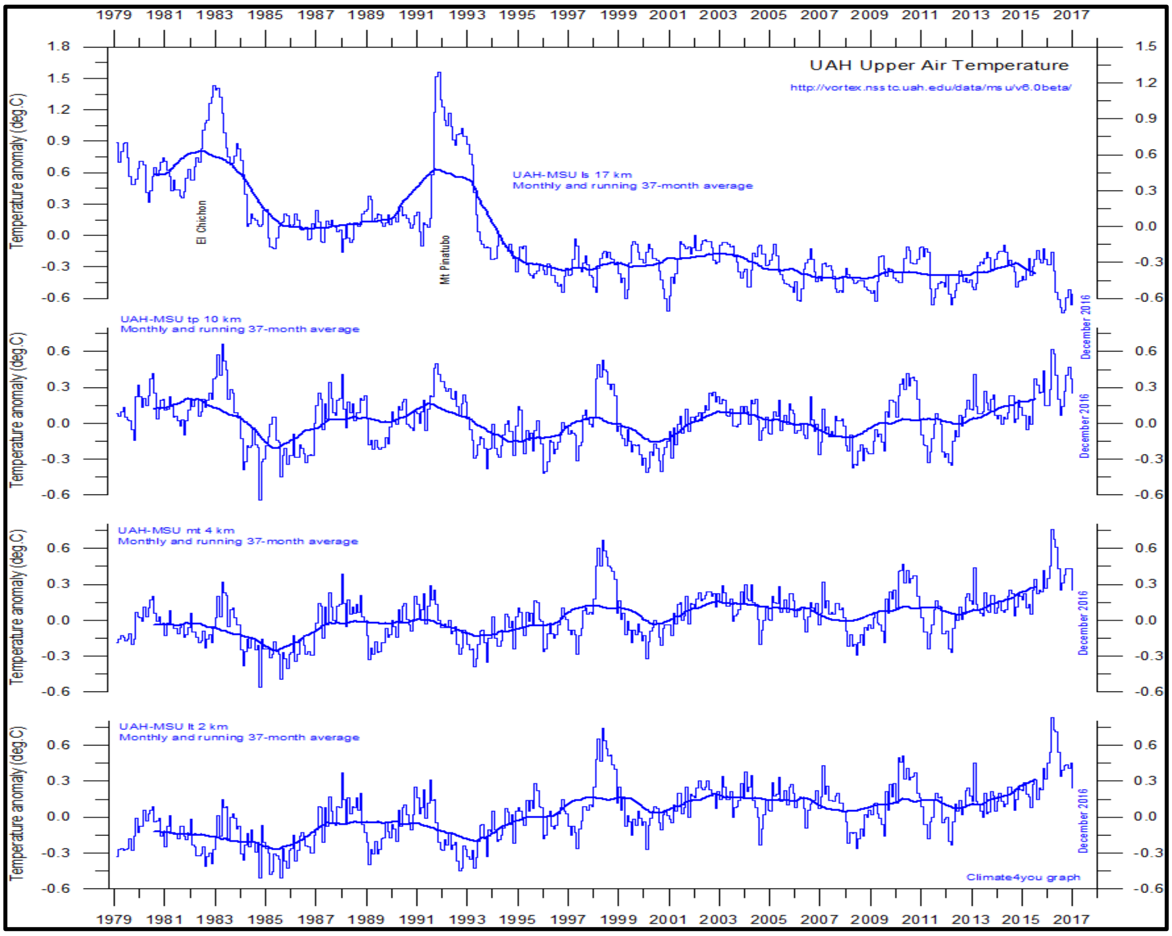


Figure 3.100 UAH MSU data from 2km, 4km, 10km and 17km (Climate4you, UAH)

Similarly, satellite data compiled by Dr Roy Spencer at the University of Alabama at Huntsville (UAH-MSU) 1979-2016 also shows no warming trend at 10km (Figure 3.100), and neither does tropical radiosonde data 1979-2012 at a height of 12km (Figure 3.101). Instead, the data reveals a consistent slight cooling trend since 1979, which is more pronounced with height above 10km, and the reverse, a warming trend which again, is more pronounced below 10km, the closer to sea level it is measured. However, in all the satellite and balloon data, there is no sign of the GHG warming 'hot-spot' which is predicted by the enhanced CO_2 hypothesis. Some problems were identified in the radiosonde network, with nine 'anomalous' stations being reported in 2003 (Angell, 2003), but correcting for these did not change the overall result for the hot-spot; however, it did double the lower atmospheric warming trend.

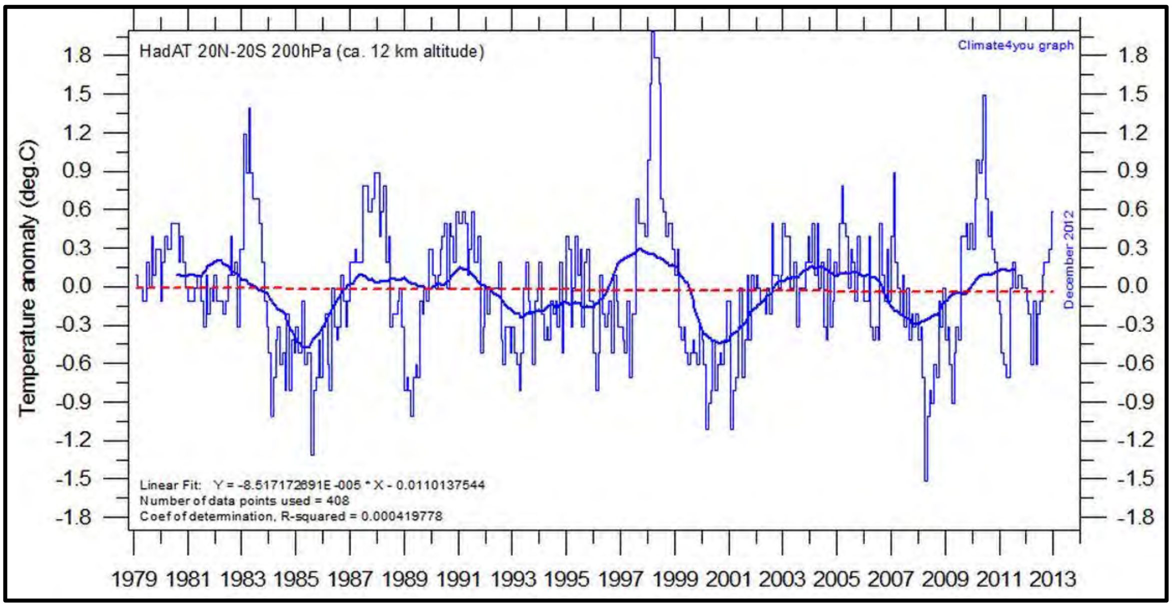


Figure 3.101 Radiosonde 1979-2012 tropics no hot spot at 12km (Climate4you HadAT)

The satellite and radiosonde measurements do show a strong trend of cooling in the regions above the tropopause, and similar spectral cooling rates found in the stratosphere and the mesosphere have been associated with increases in atmospheric CO_2 concentrations (Clough et al., 1995) (Figure 3.36). All of the above trends in data are collectively consistent with greater solar insolation forcing of the climate system at the surface, caused by a lessening of low-level tropospheric cloud cover and are inconsistent with greenhouse warming (Figure 3.15). The main question to be answered here is what is the mechanism responsible for such a change in low cloud cover.

3.8.9 Should the energy policy be changed because of the models?

This really is a question for policy-makers. Predictions of the climate future rest wholly on climate modelling. But the predictive performance of the government-funded models when compared to subsequent surface temperature data has been very poor. The most accurate actual temperature records available, are those from balloons and satellites, (Figure 3.100 and 3.101) and they show much less warming than was projected by the GCM's. However, it is said that politicians often base their decisions on economics, and hence not on possible future climate states, therefore this needs to be examined as well.

3.8.10 Economists struggle with cost/benefit analysis

Climate scientist Judith Curry has described climate change as a;

"...wicked problem" which is "ill-suited to a command and control solution"

(J. Curry & Haapala., 2014).

Economists are having trouble too, with predicting costs and benefits in this complex and uncertain field (Nordhaus, 1994). The UK government's commissioned Stern report (Stern, 2007) touted a carbon price of A$25/tonne for CO_2 as being sufficient to reduce demand substantially; but this figure was tried in Australia 2012-14 and totally failed to reduce demand. Apart from this unrealistic figure, Stern also relied on IPCC costings for global warming, and used an unrealistically low discount rate; these factors mean that his report's conclusions are erroneous. A more recent paper (Tol, 2009) has compiled 14 estimates of the economic impact of anthropogenic global warming expressed in % of GDP 'relative to today's' temperature ('today' being 2009). On average, the projection for the overall economic effects of anthropogenic global warming to be positive up to 2.2°C (i.e. until at the very least 2100), and then becoming negative (Figure 3.102).

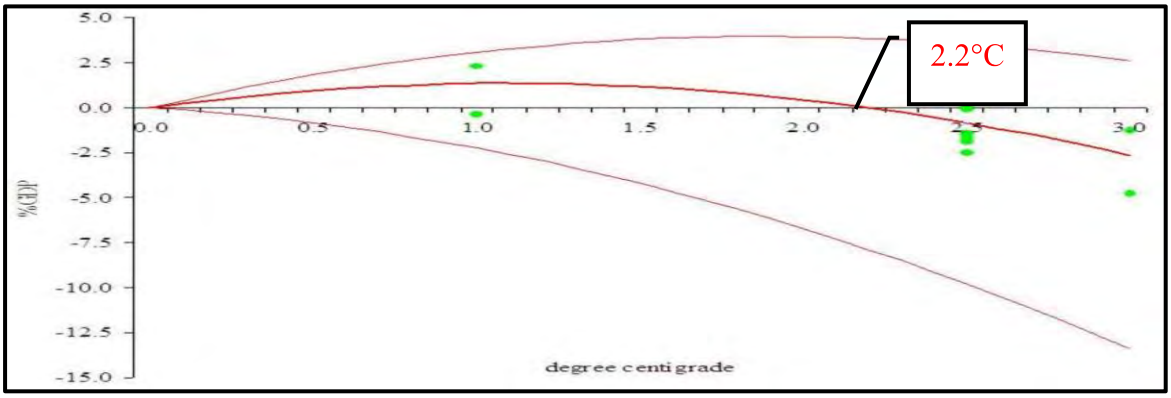


Figure 3.102 Average of 14 estimates of the economic impact of warming (Tol, 2009)

Note that the average of the 14 estimates, project net benefits in the form of such things as crop increases from CO_2 fertilisation globally, (already measured at 11%) (Donohue et al., 2013), from a warming climate in Canada and Russia and from lower heating costs in Europe and North America for up to 2.2°C of warming from a 2009 baseline. Conversely, the 2°C target set by the Paris accord (Rogelj et al., 2016) takes its baseline from the pre-industrial temperatures. According to the IPCC's AR5 (Team et al., 2014), Global temperatures in 2009 were 0.8°C above the pre-industrial temperature; therefore, according to the average of the 14 economic estimates, any man-made global warming is net beneficial, up to 3.0°C above pre-industrial levels – meaning that net benefits probably extend at least to the year 2100.

The low amount of research funding and therefore the effort which has gone into any cost/benefit analysis in the field of climate change stands in stark contrast to the billions in research monies which have been assigned to climate modelling. Economists can't even say with certainly whether the hundreds of billions of dollars being spent by politicians is too much or too little (Tol, 2009); surely more could be allocated to better establishing the facts from a financial point of view, this would obviously be well worth the investment, considering the massive expenditure currently involved in climate action.

3.9 Overview to the concern over global warming

3.9.1 Where is there general agreement among scientists?

To sum up the areas of agreement on the science in simple terms, there is certainly overwhelming evidence that CO_2 and CH_4 are what has been termed 'GHG'; that is, they capture and then re-radiate in all directions some of the upwelling long-wave radiation, which the Earth emits in order to cool off after being warmed by the Sun. The principal components of the atmosphere, O_2 and N_2 do not do this. As far as importance to the overall greenhouse effect goes, CO_2 is presently around twenty times more important than CH_4 (Schmidt et al., 2010). But the main three absorption bands for CO_2 (2349, 1388, and 667cm^{-1}) are already close to saturation at current atmospheric levels, and as has been seen, each new CO_2 molecule added to the atmosphere has less greenhouse effect than the last one added (Lindzen & Choi, 2009) (Figure 3.40). This logarithmic effect does not apply to CH_4, so the relative importance of additional emissions of these gases will change over time. The effect of higher levels of well-mixed atmospheric GHG, in the lower troposphere, is mostly agreed to be probably towards warming. There is also agreement that more CO_2 causes cooling in the Mesosphere and the Stratosphere. And there is general agreement that atmospheric levels of CO_2 and CH_4 have been increasing for some six decades at least, and that man has contributed to this increase – although there is an ongoing discussion in the literature about the extent of this contribution to the measured atmospheric changes.

General agreement also exists that there is more heat in the troposphere than might be expected. This heat can and has been measured from the surface, and has often been attributed to 'back-radiation' from GHG. Another agreed area is that there has been a period of global warming; the evidence for this is overwhelming, and the approximate date from when it started also has fairly strong support from most scientists; around 1690. Other generally agreed areas are that it was warm in the RWP and the MWP; but there is continuing discussion about whether the CWP is warmer than those, or is cooler than one or both of them. Another area of agreement is that the Antarctic has not warmed for decades, even though this is contrary to the predictions of the EGGWH. There is still disagreement on the existence or not of the so-called ‘atmospheric hot-spot’.

3.9.2 Where is there serious disagreement among scientists?

The main areas of disagreement are as follows;

- the climate sensitivity (the effect of doubling atmospheric GHG in CO_2-e terms)
- whether the projections of climate models are accurate or not
- whether cloud feedbacks are positive or negative
- on how unusual current climatic conditions are; i.e. ice melt, temperatures etc
- how fast the sea level is rising, and if this rise is accelerating or not
- on why Antarctica is not warming
- on whether the CRF affects the climate significantly or not
- on the existence and influence of solar or astronomically-induced climatic cycles
- on the significance of atmospheric auto compression

3.9.3 What about a cost-benefit analysis?

Even if it is found that the IPCC is 100% correct and a temperature rise of 2°C or 3°C above pre-industrial is in the pipeline this century that does not mean that the only course of action is to drastically cut emissions, which may potentially be so damaging to western economies, and to the poor of developing countries. The fact is that such a rise may even be net beneficial (Tol, 2009) (Figure 3.102) and so to try to stop it may not only be incredibly expensive in terms of resources and lives, but also unnecessary. It may be better to simply continue on a business as usual course, and let market forces solve any emissions issues, as they have solved other large issues before. This is exactly why a very comprehensive, international, transparent and independent cost/benefit analysis is needed, to sufficiently inform nations so that they are in a position to intelligently decide the answers to such momentous questions.

A comprehensive and independent cost-benefit analysis examining the costs vs the benefits of climate action involving massively costly emissions cuts, using means such as wind farms or roof-top solar power in return for an unmeasurable but ostensibly beneficial reduction in global temperatures has never been carried out by any Australian government, and given the data, it is not hard to see why.

3.9.3.1 Coal and gas vs wind and solar

In Australia, as in many other countries, the choice between energy sources for many people has come down to coal and gas or wind and solar. That is, between what are seen as ‘polluting’ energy sources and are seen as ‘clean’ energy sources. This is clearly a false choice in many respects.

First, the former is not as polluting as they used to be, nor are they as polluting as they are often represented in the media as being. An example is the new generation of coal plants being built in China, which emit seven times less CO_2 per unit of electricity generated than outdated plants like Hazelwood in Victoria (The Australian, 2017). And the later power sources are not as clean as they are thought to be or are often reported to be. Although it is true that wind and solar are very clean in operation, what is often forgotten is contained energy and contained pollution. With wind, pollution is generated by the manufacture of the steel tower, the forming of the massive concrete bases, and in particular the mining and manufacture of rare earths such as neodymium and dysprosium, which are needed for the turbine’s efficient operation. The average 2MW wind turbine requires 350kg of these rare earths, which are only mined in China, the mining and production of which creates not only CO_2 emissions, but massive amounts of highly toxic pollution (IER, 2017). The area around Baotou, China has been particularly affected. There are even questions as to whether wind farms actually reduce CO_2 emissions overall, compared to a combined cycle gas generator or not (Le Pair, 2011).

Second, the two sources of energy are not interchangeable, because they are not equivalent in dispatchability. Clearly, a coal and a gas plant can be switched on and off, or varied in output to suit the demand, which is constantly changing. Wind and solar are totally different, they are intermittent; and in the case of solar, often generate at the wrong times. Integrating them into the typical demand cycle, once they reach a certain percentage of generation (generally said to be 20%) is also very challenging (Energy Education, 2017). Research in Australia also finds little wind CO_2 benefits over coal, especially when wind farms are combined with gas to make them more dispatchable (Duncan Seddon, 2013).

Third, the energy density is very different. This is the amount of land which is taken up by a certain amount of generating capacity. Solar and wind require vastly more land area for the same production. This can be a real problem especially in small countries.

Fourth, figures from the U.S. energy and employment report (U.S. Energy, 2017) show the massive productive inefficiencies in wind and solar when compared to coal and gas. One coal worker produces as much electricity as twelve wind workers or seventy-nine solar workers. In addition, all these workers in renewables have to be either subsidized or the use of their electricity mandated by the government in order for their jobs to exist.

3.9.3.2 The greening of the planet

Other researchers not assessed by Tol, calculate that the net benefice is really very high (Bezdek & Driessen, 2014). In a perhaps surprising report, researched by Australia's CSIRO, has found that the Earth is in fact 'greening' (Donohue et al., 2013) because of all the extra atmospheric CO_2. They measured an 11% increase in foliage globally 1982 – 2010 (Figure 3.103). Australia's West, India and Africa's Sahel were particular beneficiaries.

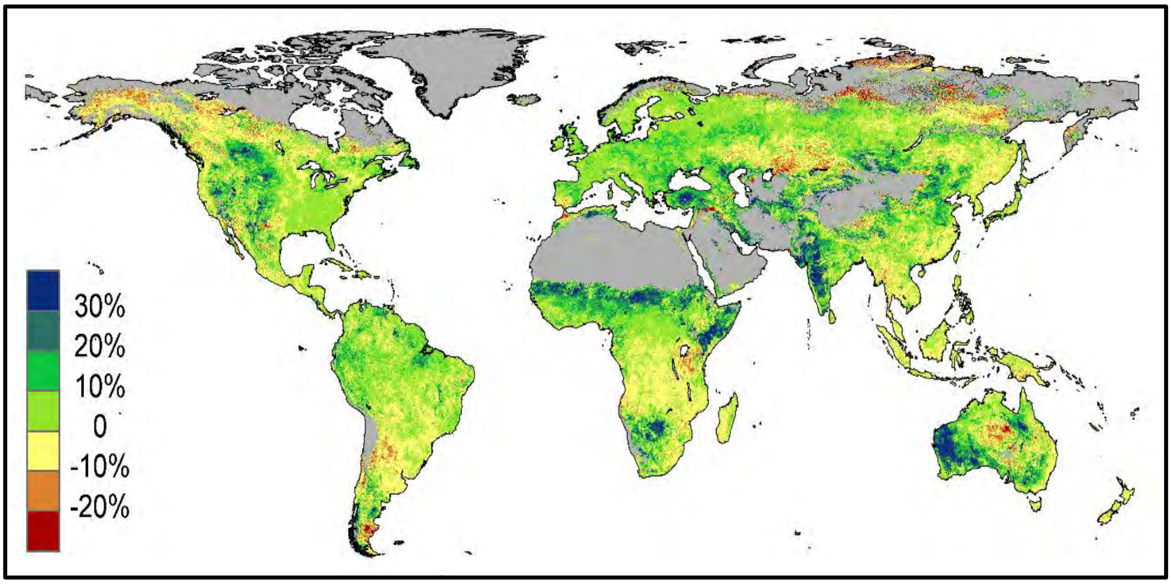


Figure 3.103 CSIRO the greening of the planet 1982-2010 (Donohue et al., 2013)

Father and son researchers Sherwood and Craig Idso have researched extensively into how crops respond to increased levels of atmospheric CO_2, with the confirmed result that many crops respond well to up to 1,500ppm CO_2, and often exhibit large (S. B. Idso & Idso, 2001) increases in growth of ~30%, and with a reduced need for water.

Large growth in crops has also been found in a department of energy research program (Cure & Acock, 1986) into the effects of a doubling of atmospheric CO_2. The average increase in crop yield was 41%, with 52% initially, this dropping to 29% after acclimatisation. The fertilising effect of the observed atmospheric increase in CO_2 on crop growth over the last several decades, is thought to have resulted in sufficient extra crop production to feed another 500 million people (Bjørn Lomborg, 2007).

3.9.3.3 The sources of gobal CO_2 and CH_4 emissions

The main sources of global CO_2 and CH_4 emissions has been recorded in a series of measurements by the sciamachy detector (Buchwitz et al., 2005), carried on the European envisat satellite (Figure 3.104 and 3.105). The main sources are rainforests, rice paddy fields and wetlands; these sources were confirmed by later work (Buchwitz et al., 2013).

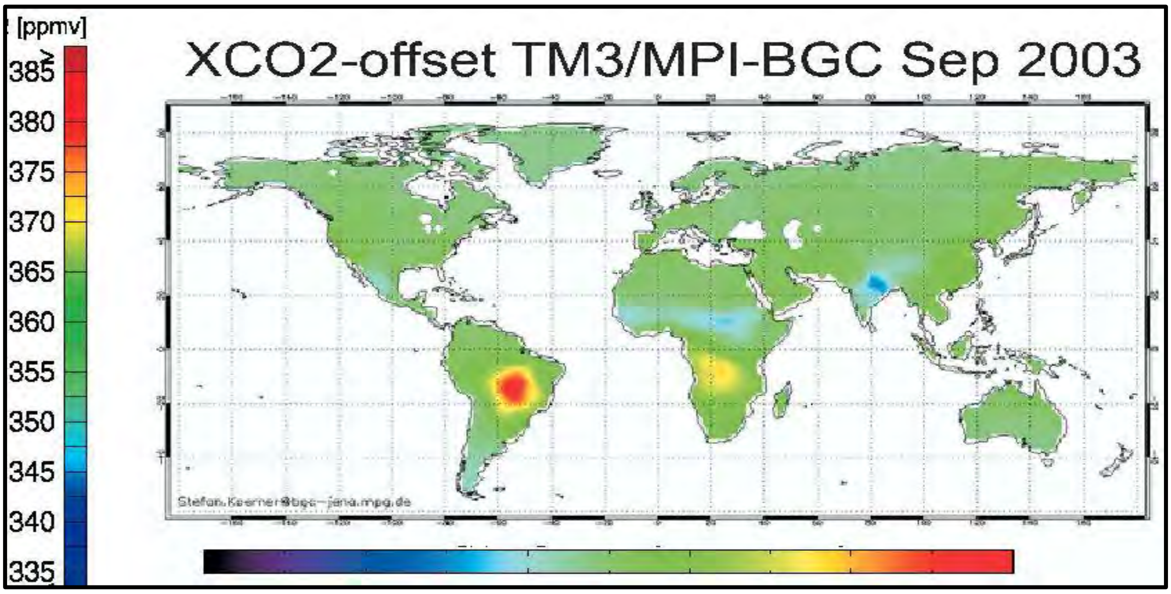


Figure 3.104 Global CO_2 emission sources September 2003 (Buchwitz et al., 2005)

The main CO_2 emissions sources on land are shown in Figure 3.104 and are; the Amazon basin, central Africa and Indonesia. The mains sources of CH_4 emissions from land are shown in Figure 3.105 and are; central Africa, India, Indochina and southern China. Relatively few large sources show up outside of these areas at this time of year.

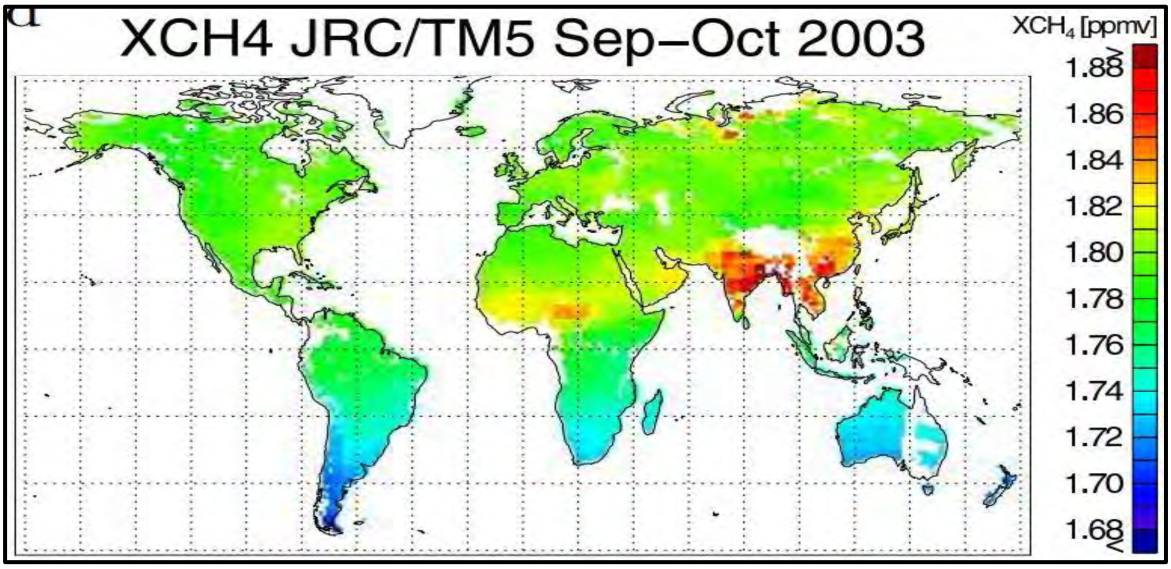


Figure 3.105 Global CH_4 sources September-October 2003 (Buchwitz et al., 2005)

3.9.3.4 Geoengineering – is it the answer?

The cost of the Paris agreement and subsequent agreements will be truly enormous, counted in the many trillions of dollars (Bjorn Lomborg, 2014). Several scientists have proposed geoengineering as the cost-effective solution to man-made global warming in the 21st century – should it occur. One such proposal is to deploy boats on the oceans (Bickel & Lane, 2009) which have the capability to spray a fine mist of seawater upwards; this would form more and whiter clouds, so reflecting Sunlight. As mentioned earlier, a 1% change in the albedo of Earth would easily be enough to counter all the anthropogenic forcing from a doubling of atmospheric GHG concentrations. The cost of the albedo-changing boats is estimated at just A$9 billion.

3.10 Conclusion to the science of global warming

The conclusion has to be that the science is not settled; it is in fact far from being settled. Whether actions are needed or desirable to reduce anthropogenic GHG emissions is a matter for policy-makers – with the proviso that they must now be given a fuller picture of the true state of the science as it exists in the scientific literature. It is patently obvious that a 'Team B' is required to counterbalance the biased reports which are being issued by the UN's climate body, the IPCC. Given that the current state of the science in the literature is clearly very different to how it's actually being portrayed in the IPCC reports, in the mainstream media, by most NGO's and by most of academia, this is essential.

Responsibility for who this Team B is or how it is to be arranged will probably fall on the current U.S government, since it is unlikely to be a priority - or to be in the interests of any other prominent body, national or international, private or public. The informed populace of the West should demand that their governments provide evidence-based science, and not that which is clearly biased or that which has been provided by a wholly political body. It is also true that far too many stellar organisations have relied exclusively on the UN's IPCC climate reports for far too long, without independently checking their results. The costs involved in climate action are so enormous, in resources, in human capital and in finance that common sense demands a Team B, and also demands a separate, independent and a comprehensive cost/benefit analysis. It is far better to proceed from a position of knowledge than to act simply out of ignorance and fear, as appears to be the case now.

4 Chapter 4: The politicisation of climate science

4.1 Context - the International Community and Climate Action

The context of the need for emissions reductions in Australia in the first place, is based on the international community's reaction to the science of climate change, and in our interactions with the international community, through the United Nations. The politicisation of the science of climate change throughout the Western countries, and in particular in the United States, has a strong influence on the level of international action actually taken to combat climate change. This in turn, strongly affects what action Australian governments take. The actions taken by the Australian government on emissions at home, can only be understood or predicted by looking at the overall international political scene with regards to climate. This research is primarily about reducing fugitive emissions from coal mines cost-effectively, but the level of present and future political and public desire to do this comes directly from the pressures in the international scene. These cannot be understood without some knowledge of both the present state of the science of climate change, and the politicisation of climate change science which has and is taking place.

4.1.1 The social cost of carbon

According to the U.S. EPA, (U.S. EPA, 2015) there is a 'hidden' cost to emitting 'carbon' into the atmosphere. This long-term damage includes the physical, ecological, and economic impacts of climate change, and has been assessed by the EPA for CO_2 to be US$36/t and for CH_4 (Marten, Kopits, Griffiths, Newbold, & Wolverton, 2015) to be US$1,000/t in 2000 dollars. These and other, preceding EPA figures, were used by the Obama administration to formulate national energy policy; leading directly to decisions like the clean power plan (Bushnell, Holland, Hughes, & Knittel, 2015), which became known as Obama's 'war on coal'. Another report (Stern, 2007), commissioned by the government of the U.K., included some suspiciously high figures for the social cost of carbon (SCC) (US$314/t for CO_2), and yet these were still used as a guide for governmental policy decisions on energy.

But were these EPA and Stern figures correct? Is there really a large and hidden cost to emitting GHG? Like many areas in the field of climate change, this is strongly disputed in the literature. A meta-analysis of 200 estimates of the SCC by economist Professor Richard Tol found the U.K. government's Stern report to be an outlier, and Tol even describes the analysis in it as 'dodgy'. Tol also found that the average SCC in the reports is still so high, that they would result in the complete collectivisation of economies if it were to be converted into a tax. Just 13 of the 200 assessed studies actually found the SCC to be negative, in other words emitting carbon dioxide is of a net benefice to both the environment and humanity. Perhaps it's possible that most economists are simply unaware that carbon dioxide is, in fact, plant food and more of it in the atmosphere has large crop growth benefits among others. Recent work has found that the mean SCC of published estimates is US$12/t for CO_2 at a 3% rate of time preference, and US$98/t for CO_2 at a 1% rate; this compares to the average private benefit provided by fossil fuels of US$411/t for CO_2 (Tol, 2017). In effect meaning that the use of fossil fuels results in a large net benefice.

4.1.1.1 Why is there a 2°C goal, which was set in Copenhagen at COP15?

A target of 2°C above the pre-industrial levels was not mentioned until the late 1990's and not set as a target maximum by international negotiators until COP15 in Copenhagen. Professor Tol has argued that this figure seems somewhat arbitrary (Tol, 2007); however, this figure has been central to all international negotiations since COP21, and the number was defended by EGGWH proponent Professor Mann (Mann, 2009) because it was necessary to avoid what he termed; "dangerous anthropogenic interference" in the climate system. According to the UNFCCC achieving the <2°C of warming goal will be difficult, since the aggregate emissions after the cuts so far submitted by participating countries, still amount to 55Gt CO_2-e/yr; and the IPCC says that <40Gt CO_2-e/yr of emissions will be required (UNFCCC, 2016).

4.1.2 The United Nations framework convention on climate change

What is the UNFCCC? It is an international environmental treaty which came out of the Earth Summit meeting in Rio de Janeiro in June 1992, which entered into force on 21 March 1994. The stated objective is;

> *"The ultimate objective of this Convention and any related legal instruments that the Conference of the Parties may adopt is to achieve, in accordance with the relevant provisions of the Convention, stabilization of GHG concentrations in the atmosphere at **a level that would prevent dangerous anthropogenic interference** (my emphasis) with the climate system. (UNFCCC, 2016)"*

This short statement reveals the UNFCCC believes that several notions are either thought to have been scientifically proved already, or are to be assumed to be factual;

i. that humanity can stop atmospheric GHG concentrations from changing

ii. that it's human GHG emissions which have caused all of the recently observed rise in all atmospheric GHG
iii. that the atmospheric GHG concentrations would continue on their upward trajectory if humanity does nothing about them
iv. that if humanity 'allows' the concentration of atmospheric GHG to continue upwards, then this would severely and adversely affect climate on earth
v. that this adverse effect would reach 'dangerous' levels if nothing is done
vi. implicit in the statement, is that the costs to mankind and the environment of inaction, would be greater than the costs of action

In reality, none of these six notions have been scientifically proved beyond doubt.

4.1.2.1 Conference of parties (COP) meetings and their aims

COP takes place annually, have 197 participating parties, and their aim post COP21 is to assess the progress that is being made towards the Paris target of limiting man-made global warming. In the IPCC reports, such as in AR5, global temperatures are stated to be directly related to atmospheric GHG levels (Figure 4.1). Yet as outlined previously there is a veritable mountain of scientific evidence that this idea is completely wrong. Nevertheless, the entire Paris climate accord and its targets are built upon the accuracy of this idea.

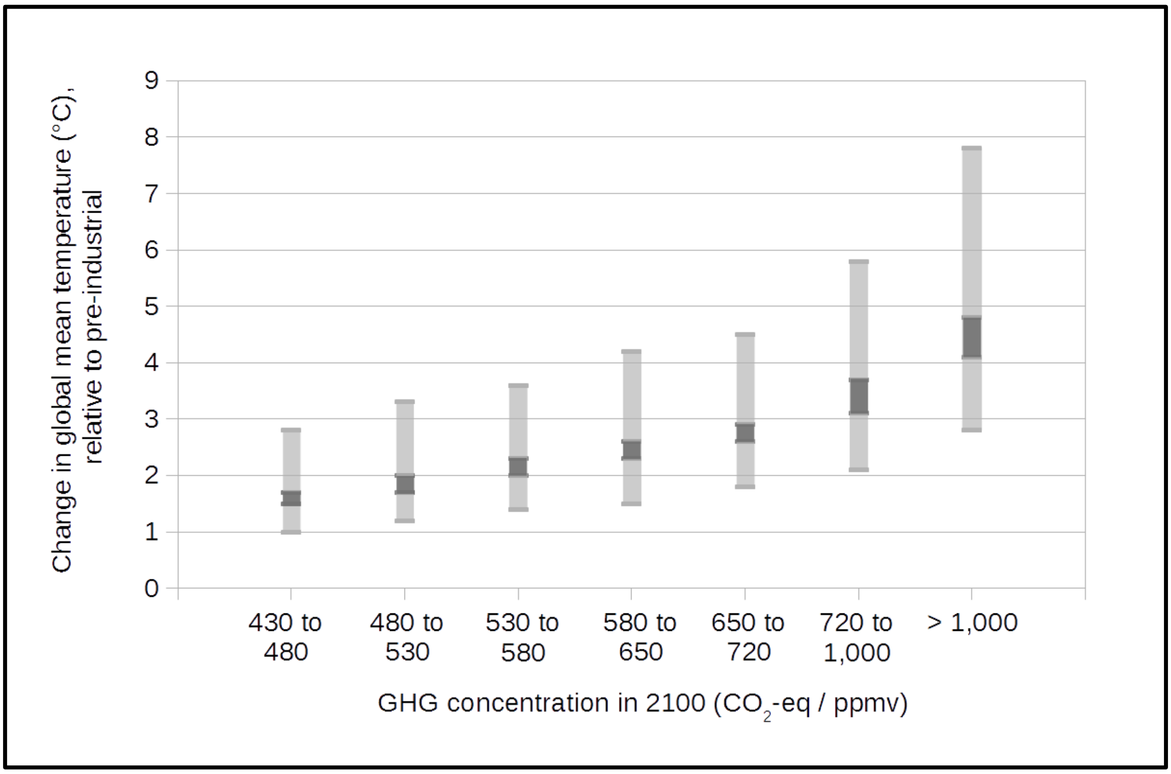


Figure 4.1 In the AR5, temperatures are directly related to GHG (Team et al., 2014)

4.1.3 The international community and the UNFCCC

4.1.3.1 What is the stated aim of the UNFCCC'c climate action plan?

The stated aim of the COP21 (Rogelj et al., 2016) (Robbins, 2016b) meeting in Paris is to keep the post-industrial global near-surface temperature rise to below 2°C. Currently, anthropogenic CO2-e emissions are approximately 38Gt/yr; according to the climate sensitivity range as set out in the AR5 report (Team et al., 2014), global emissions will need to be cut even more than the current Paris agreement trajectory, which is projected to be 55Gt/yr by 2030. This figure comes from totalling the nationally determined contributions which have been pledged thus far by participating nations (UNFCCC, 2015).

4.1.3.2 Which countries are not taking action to cut emissions and why?

Those participants which fall into the category of 'developing countries' and others which are defined as rapidly developing countries, termed the BRIC group (led by Brazil, Russia, India and China) even though they collectively emit more greenhouse gases than the 'developed' countries do, they are not required to take strong action to reduce, or even to stabilise their emissions at current levels. BRIC is led by the world's largest emitter by far, China. Perhaps surprisingly to some, the COP21 agreement fails to recognise that most anthropogenic emissions actually now come from developing countries; either in its report, or in its agreed actions to reduce emissions.

4.1.3.3 Which countries are taking the most action to 'stop' climate change?

In the report of the Paris agreement, COP21 (Bodansky, Hoedl, Metcalf, & Stavins, 2016) again the UNFCCC have directly linked CO_2 emissions to global temperatures by saying that a cut to below 40Gt CO_2-e per year will be required by 2030 in order to keep the post-industrial rise to below 2°C. The brunt of the emissions cuts is expected to be borne by the 'developed' countries, mainly western democracies – those in the Western European and others group (WEOG), even though the emissions of the BRIC group are far higher. If cutting anthropogenic GHG emissions is the real aim of the Paris agreement, this is certainly an ineffective way to go about it.

4.1.4 The morality question of global warming/climate change action

The morality and the ethics of climate change action, like many questions related to climate change, is vexatious and has diametrically opposing viewpoints. A recent Australian prime minister has said that;

"Climate change is the great moral challenge of our generation".
Kevin Rudd on August 6th, 2007 (Australian Politics, 2007).

By this he meant that immediate action must take place to prevent dangerous man-made climate change from happening and impacting populations, mainly the world's poor; yet less than 3 years later he dropped his government's commitment to their signature policy on climate action, the carbon pollution reduction scheme, (CPRS) (Fernandes & Holmes, 2010) this back-flip quickly resulting in his demise as the Australian prime minister.

4.1.4.1 Growing political and climate activist violence in the United States

The question of morality has also been brought up on the sceptical side, often by prominent Alabama state climatologist John Christy in relation to the plight of the poor in Africa, who are being denied access to cheap, reliable fossil-fuelled power by multi-national bodies backed by NGO's and climate activists. Christy is one of the prominent people listed as a 'denier' by activist groups such as President Obama's organising for action (Organising for Action, 2017). The building where Christy and another sceptic of EGGWH, climate scientist Roy Spencer work at the University of Alabama in Huntsville was targeted by a gunman on Earth day, 22nd April 2017. Seven shots hit the 4th floor where Christy's office is located (Environmental News, 2017). In another incident involving the targeting of more of the many listed climate 'deniers' on Obama's website (Figure 4.4), republican members of congress were targeted by a Burnie Sanders supporter at a baseball field, resulting in one death and four injuries. House republican majority whip Steve Scalise was seriously injured in the firefight (CNBC, 2017).

4.1.4.2 Global warming and extreme weather; death rates fall

The UNFCCC has asserted that human well-being is already worsening because of man-made climate change in Asia (UNFCCC, 2015). An increase in the frequency of extreme weather events in that region has also been claimed (Yumul, Cruz, Servando, & Dimalanta, 2011). However, this has been strongly refuted, data from EM-DAT shows that the cumulative death rate from all extreme weather events has dropped dramatically - by 98% in fact in the last 100 years (Goklany, 2009c) (Figure 4.2). The UNFCCC claims appear to be refuted; on the contrary in fact, human well-being has only recently begun to suffer – and this is because of climate action, not man-made climate change (Goklany, 2009c) (Goklany, 2011) (Montford, 2015) (Group, 2012).

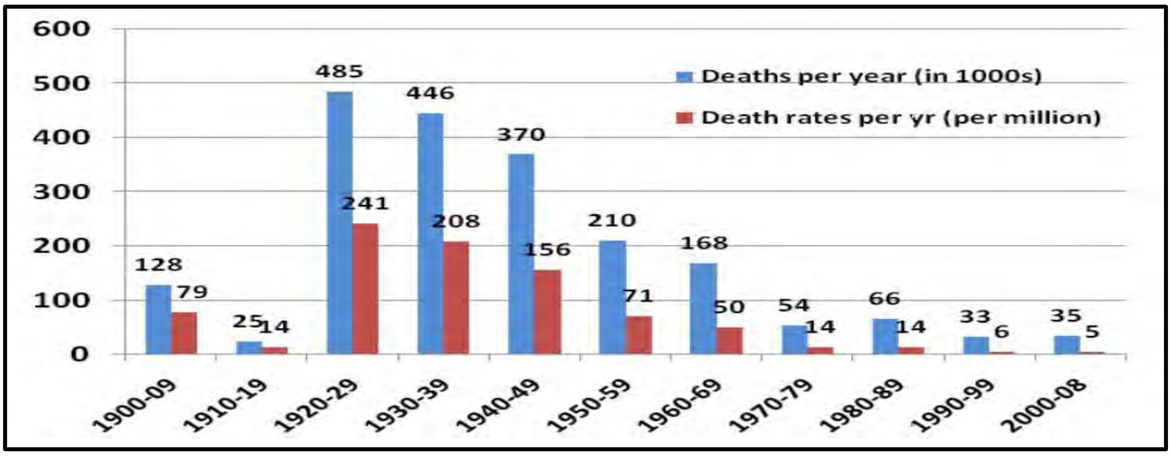


Figure 4.2 Death rates from extreme weather have declined strongly (Goklany, 2009c)

Frequency data from extreme weather events such as droughts, storms, hurricanes, tornados or cyclones show no increase which may be related to increased atmospheric CO_2 concentrations. Typical of these is tropical cyclone landfalls, updated 2015; (Weinkle, Maue, & Pielke Jr, 2012) (Figure 4.3).

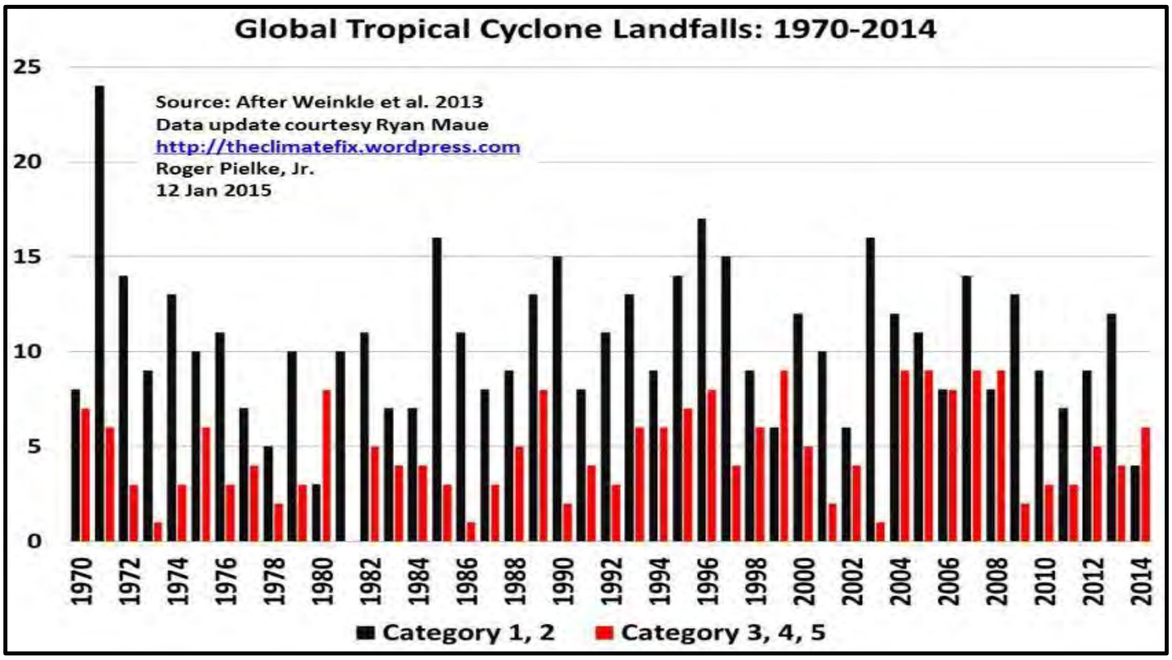


Figure 4.3 No change in tropical cyclone landfalls 1970-2014 (Weinkle et al., 2012)

4.1.4.3 Deaths due to climate action increase rapidly

The opposing viewpoint to the UNFCCC has seldom been widely publicised in the main-stream media, but the arguments are at least as strong morally. Can taking actions now which results in the deaths of millions of people, be justified on the basis that millions of others *may* be saved in 100 years' time by those very actions? The facts are that several million of the world's poor have already died directly from climate change action, and at least 35 million more have been pushed back into extreme poverty by that action (Group, 2012). Specifically, from the mandatory use of ethanol and the diversion of crops to biofuels in an effort to cut CO_2 emissions. The estimated death rate from starvation caused by the higher food prices because of biofuels as of 2010 is ~192,000 per year (Goklany, 2011). In a belated response to this unintended effect, the European Union has pledged to cut its ethanol mandate in fuel from the present 10% to 5% by 2020 (Mosnier et al., 2013).

Tens of thousands in the west are also dead as a result of climate action. Like the biofuels situation, these deaths may be an unintended consequence, but this fact will not bring those people back. In developed countries, the deaths due to climate action are mainly a result of fuel poverty, not starvation. The numbers are large; for example, in the UK, 'excess' winter deaths were 158,880 over the five winters 2010-2015 (Chilled to death, 2015) (Simcock, Walker & Day, 2016). Reports exist of UK pensioners being so fearful of their energy bill, that they are burning cheap books from charity shops in order to keep warm (Metro, 2010). The EU fares no better in relation to fuel poverty, soaring energy prices due to the EU-mandated move to renewables has now created a situation where between 50 and 125 million are 'unable to afford proper indoor thermal comfort' (Atanasiu, Kontonasiou & Mariottini, 2014).

4.1.4.4 World's poor targeted by NGO's and UN bodies

Severe indoor air pollution is prevalent in many developing countries, where hundreds of millions of people are energy-poor. This pollution comes from the burning of wood or dung for heating and cooking, results in deforestation, disease and an early death for an estimated 1.6 million people - mainly women and children - every year, (Smith, Mehta, & Maeusezahl-Feuz, 2004) most of them in Africa. It is also known that the inability to access affordable electricity contributes substantially to poverty like this existing in Africa (Deichmann, Meisner, Murray, & Wheeler, 2011). Yet the provision in Africa, of the cheapest form of reliable energy, fossil fuels, is actively being prevented by the United Nations, the World Bank, the OECD's International Energy Agency (IEA) and the European Union, ostensibly out of fear from the climatic impact of the resulting CO_2 emissions. Many climate activist groups (Bugaje, 2006) such as Greenpeace, 350.org (350Africa.org, 2017), world wildlife fund and many others are not only heavily involved in the IPCC, but also involved in preventing Africa's development in many ways. For example, they lobby governments and banks to stop the funding for power station construction (Driessen, 2007). Their aim is not to help people develop, but instead to promote a UN goal called 'sustainable development' which essentially restricts Africans to renewable energy, so keeping them in abject poverty. The typical opinion of Western activist groups appears to be;

"...the only option for most African countries is the development and harnessing of the available renewable energy resources" (Bugaje, 2006).

Over the last several decades, Africa has already suffered grievously at the hands of environmental groups; first, their activism caused DDT to be banned across the continent, costing an estimated 30 million lives to malaria (Attaran & Maharaj, 2000). Then activism pushed by global warming fears, drove governments to mandate ethanol use in most Western countries, hitting Africans hard with soaring food prices – and causing starvation and death on a massive and unacceptable scale (Goklany, 2011).

The IEA appears to be of the same opinion. In 2009, the IEA allowed Yvo de Boer, then the secretary of the UNFCCC to write a part of its annual report. In his section, he stated that emerging countries should never increase their per capita CO_2 emissions – even though they now stand at just 1.4t/y/person. This is less than 10% of the emissions average in 'developed' nations and would be certain to condemn billions of the world's poor to remain in abject poverty.

4.1.4.5 Climate science action and eugenics

Another calling for caution on climate action is Professor Richard Lindzen, one of the planet's top atmospheric physicists who has been heavily involved in the IPCC process and its reports. Lindzen's 1995 paper, 'Science and politics: global warming and eugenics' (Lindzen, 1996) is unusual for a scientist to write, but fearlessly lays out the moral case against man-made global warming, comparing the interaction of science, advocacy and politics with the rise of eugenics in the 19th and early 20th century. The parallels between the actual actions that are being called for by climate advocates and those of eugenics, and Soviet Lysenkoism in the 1930's is striking. It is sobering to note that the current president (December 2016) of the United States' senior science and technology advisor, Professor John Holdren is not only an advocate of strong climate action, he is also the co-author of a 1977 book in which he advocated population reduction (Ehrlich, Ehrlich, & Holdren, 1977) through the doctoring of public drinking water and other horrific means like forced sterilisations and forced abortions. He also advocated the removal of all illegitimate babies from their mothers – this is very reminiscent of the techniques actually used by the now-discredited late 19th century eugenicists in a dozen Western countries. It is worrying that someone who is a misanthropist/Malthusian and believes in such draconian and totalitarian ideas could have been promoted in the 21st century by the President of the United States to this high office in the white house. The policy of the United States under President Obama since 2009 (Ulmer, 2012) has been to fund sterilisation and abortions in Africa (Zubrin, 2012) through the UN's fund for population control; (UNFPA) John Holdren was instrumental in setting this organisation up and arranging start-up funding. Similar procedures were also funded in the US, through organisations such as the population council and planned parenthood.

The early 18th century ideas and policies advocated by Thomas Malthus, and carried out against India and Ireland resulting in millions of deaths should be avoided if possible in the 21st century; hopefully, humanity is a little more enlightened today. The funding of sterilisation and abortions in Africa by U.S. taxpayers continued until an executive order (CNN, 2017a) by new president Donald Trump ended the practice on the 23rd January 2017; he effectively re-instituted former president Ronald Reagan's 'global gag rule' which states that any overseas organisation receiving funding from the U.S. taxpayer, must not have anything to do with abortion (Tebbel & Watts, 1985).

4.1.4.6 Africans and Indians are a primary target of climate activists

Africans are a primary target of European and American non-governmental organisations (NGO's) and climate advocates. In the words of one African; 'Someone wants to stop the African dream (of development)'. These NGO's frequently lobby against coal fired electricity for Africans (P. Bond, 2012) (M. Michaels, 1992) - so keeping Africans in perpetual poverty. Groups like Greenpeace provide African villagers with a small solar panel which can only power a single light globe for a few hours, while preventing them the benefits of full development via a reliable mains electricity supply. Meanwhile, western governments provide free sterilisation and abortion services to the villagers as they are lectured by NGO's that their populations are growing too fast. This certainly could be objectively viewed as being nothing but a disgusting form of racism or worse. Yet it is well documented that the quickest and the best way to rapidly reduce population growth is to quickly develop (Myrskylä, Kohler, & Billari, 2009).

Similar things are happening in India; there, the locals want full mains electrical power, provided through fossil fuels but multi-national NGO's are actively preventing this from happening (Colagiuri et al., 2012) (Grech et al., 2015). Preventing the start-up of the Indian-owned Carmichael coal mine in Queensland is another clear example of the anti-human activities of green NGO's. If allowed to proceed, this mine would ship all its coal to India, which is slated provide electrical power for 100 million Indians, lifting them out of abject poverty. Instead, the mine has been subjected to expensive and vexatious litigation by green activists, preventing its start-up for many years and costing the owner, Adani, billions of dollars. This raises the question; who is funding this anti-coal litigation?

4.1.4.7 Who is funding the anti-coal activism seen in Australia?

Mining is a business, the object of which is to make a profit. However, when doing business in modern Australia, mine owners need to not only pay all their federal taxes, state royalties and adhere to state and federal laws and environmental regulations, but to listen to stakeholder concerns. The local community and stewards of the land such as aboriginal groups, especially if they are the traditional owners of the land being mined will want to be closely involved in the project. A wise mine management will have regular meetings with these stakeholders. Common but normal concerns raised are noise, air-borne pollution, traffic, securing aboriginal artefacts from destruction, and ground or surface water quality. Mining in a developed country today, involves a high level of responsible environmental stewardship; in addition, coal mining can face activism, court action and long approval delays. A more recent concern is the level of GHG emissions; today, concern - and action such as litigation against new Australian mines can often come from overseas actors (Sullivan, 1989) (Gleeson, 2016).

A case in point is the planned Adani mine in Queensland, which has passed both state and federal approvals and must comply with 200 environmental conditions to go ahead (The Australian, 2016). The Adani (Carmichael) mine in Queensland is a A$16 billion project, is planned to provide 10,000 jobs in Queensland and importantly, supply enough base-load power in India to pull 100 million of their poor out of poverty. Yet the project is still being delayed by what has been described as vexatious court action, and has been for 6 years. The court action is being partly funded by foreign parties; links have been found to the green activist group the Sandler foundation (The Australian, 2016). This well-financed foundation is one of many in the USA which is very active in climate matters globally. Yet the Sandler Foundation lists as its mission;

"We invest in strategic organisations and exceptional leaders that seek to improve the rights, opportunities and well-being of others, especially the most vulnerable and disadvantaged"
(Sandler Foundation, 2016).

Preventing 100 million poor Indians from getting reliable electricity that will lift them out of grinding poverty, hardly seems to be consistent with this stated mission. The litigation carried out by small front organisation the Mackay conservation group (Lester, 2016) financed through an Australian body called the sunrise project – a group, in turn, financed by the giant tax-exempt U.S. Sandler foundation, is linked to John Podesta, Hillary Clinton's 2016 campaign manager (The Australian, 2016). Podesta was former president Obama's personal counsellor and was associated with the Clinton administration before that. Podesta visited Australia in 2016 and met with the activist groups opposed to Australian coal mining, and specifically the proposed Carmichael coal mine was targeted. This vexatious legal action has not only kept 100 million of the world's poor in the dark, it has held up projects that the Indian government estimates is costing 2 to 3 per cent of India's gross domestic product (The Australian, 2016). Also affected has been the Queensland economy, through the loss of royalties, taxes and employment.

4.1.4.8 U.S. Senate exposes the funding of activist groups

A U.S. Senate report titled; 'How a club of billionaires and their foundations control the environmental movement and Obama's EPA' was published in 2014 (U.S. Senate, 2014). This report was published on July 30, 2014 and details who is involved in funding the environmental movement and why. Overall, the scale of the funding in the climate fight is staggering; giving USA lists US$80,427,810,000 given 2000-2012 by foundations to green groups (Giving USA, 2016). According to the Senate report, the funding surpasses US$100 billion during the period 2000 – 2016. It can be fairly said that the general attitude of most if not all of the activist groups funded by this money is anti-fossil fuel production and many are actively opposed to any coal mining.

John Podesta and billionaire Herbert Sandler have also worked together to found climate activist groups such as the centre for American progress and media matters. Another left-wing billionaire, George Soros, advocates against the nation-state and for what he calls 'open societies and open borders'; he heavily funds activist groups and individuals such as Greenpeace, getup, open societies, the occupy movement, move on, friends of the Earth, anti-police activists black lives matter, the violent activist group ANTIFA, the white helmets in Syria, the international monetary fund, world bank, Barack Obama, Hillary Clinton, President Erdowan of Turkey, Al Gore, Maurice Strong, IPCC, UNFCCC and many, many others. Under the politics of climate change action, most of the media, almost all academia, the hard left, green activist groups, anarchists, Leninists, Marxists and Maoists, multi-national green NGO's the UN, EU and many anti-democratic forces all find common cause. Opposing this juggernaut are a handful of retired scientists, and a few poorly-funded NGO's such as the IPA in Australia and heartland in the United States.

4.1.5 How did climate science become so politicised? Role of the IPCC

The UN is a wholly political body, and since it took up the challenge of investigating the science of climate change itself by instituting the UNFCCC and more particularly the IPCC to do this and to write detailed, regular scientific reports, accompanied by very much shorter summaries for policy-makers, it seems obvious that this particular field of scientific endeavour would and has become politicised. The IPCC's 1998 governing principles charter clearly states the reason for its existence;

> *"The role of the IPCC is to assess on a comprehensive, objective, open and transparent basis the scientific, technical and socio-economic information relevant to understanding the scientific basis of risk of human-induced climate change, its potential impacts and options for adaptation and mitigation. (IPCC, 1998)"*

In other words, the IPCC was <u>not</u> set up to investigate the range of climate change (in the traditional sense) or natural climate variability (McLean, 2007) at all; neither was it set up to investigate whether human-induced climate change exists or not, or why temperatures were rising. Man-made climate change was assumed to be happening already; the investigation was to be into the extent and the impacts of it, and how to adapt to it or to prevent excessive danger to humanity or the environment using co-ordinated international action to reduce anthropogenic GHG emissions.

All three working groups were set up together; WGI investigating the science, WGII investigating vulnerability, consequences and options and WGIII investigating limitation and mitigation options. How did they know that an assessment of consequences and mitigation options would be needed, before they had done the science relating to attribution? Why would this course of action be followed, unless the basic outcome of the scientific investigation by WGI had already been decided? As has been pointed out previously in this paper, no serious assessment or consideration of natural climate variability has ever been done by the IPCC, and many significant papers on this subject which are in the scientific literature, have been ignored in all IPCC reports. These hundreds of papers constitute what many are now calling 'the missing science' (Plimer, 2009).

4.1.5.1 The missing science

The Sun, which logically is responsible for almost all (Khilyuk, 2003) of the Earth's temperature and its temperature variability, was hardly investigated. Surprisingly, until 2013, only one solar physicist (Judith Lean) out of the 1,200 contributing scientists was closely involved in the IPCC's main scientific reports. It is out of this voluminous report that the much shorter 'summary for policymakers' is produced. This is a ~30-page summary which contains the main highlights and is run past representatives of each of the participating countries governments – and parts of it are often changed by their bureaucrats prior to publication, scientists do not participate in this process. This is just one of the stages where politics can be injected into the IPCC process and into these nominally scientific summaries. Another place is in the UNFCCC reports, such as the Paris agreement report from COP21 (Robbins, 2016a) which, before mentioning climate change at all, states the importance of the adoption of a UN resolution entitled;

"Transforming our world; the 2030 Agenda for Sustainable Development" (Assembly, 2015)

A question might reasonably be asked; if the main concern is about anthropogenic GHG emissions and reducing them, why aren't these scientific concerns the main subject of the agenda? Many prominent persons have warmed of the dangers when politics and science are mixed in this way, including Carl Sagan, Sir Paul Nurse, President Eisenhower and author Michael Crichton;

"The mixing of politics and science has historically had severe dangers associated with it" (Crichton, 2003).

Considerable material relevant to the science of climate change, and sourced from the peer-reviewed literature has been used in this work in chapter three; why isn't it in any of the IPCC's reports? Is the reason this 'missing science' is missing, political? If so, a more balanced approach is purposefully taken here. In the field of climate change, published peer-reviewed papers from scores of scientists who are so-called 'sceptics' permeate the scientific literature, and many of these have been presented here, and have been discussed in significant detail as to their relevance and importance.

4.1.5.2 Where politics and climate change meet; NOAA, GISS and NASA

Investigations into NOAA's climate activities have been undertaken for several years by a U.S. House committee responsible for oversight; the committee on science, space & technology (U.S. House, 2017) under Chairman Lamar Smith. Like GISS, NOAA is a part of NASA, and in recent years NASA's work on space has been reduced while its work on climate change has increased enormously. The funding allotted to climate at NASA under President Obama rose and is now more than US$2 billion per year (Teel, 2013) and so NASA is much more reliant on government climate research funding than it used to be.

4.1.5.3 Political gap on the environment widens after 1990

The gap between republicans and democrats in the US on the environment has been growing since the first UN IPCC report was published in 1990. That gap is now a chasm:

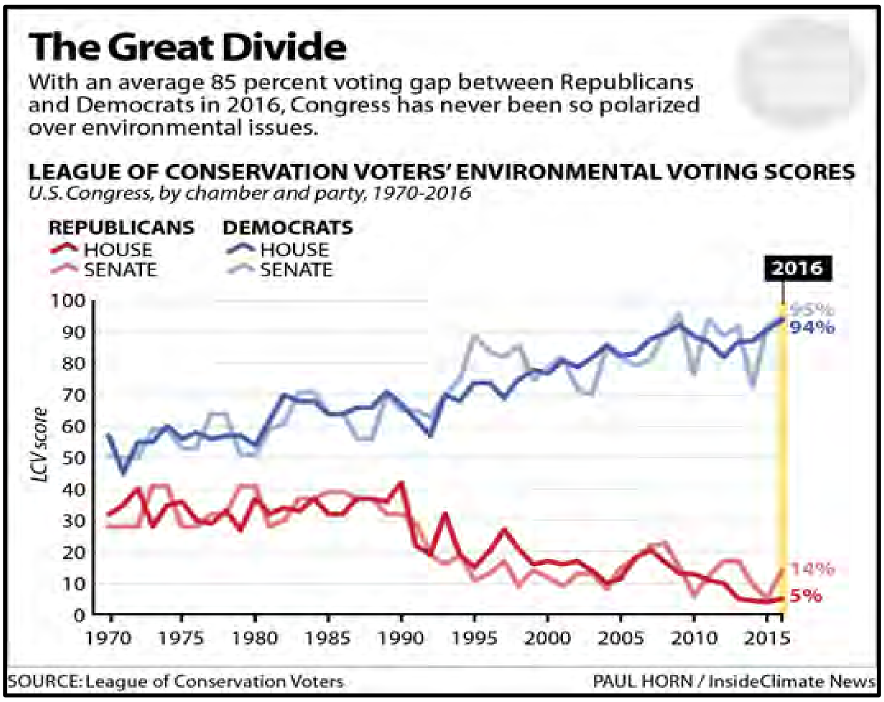


Figure 4.4 Political polarisation on environment grows (League of C.V. 2016)

4.1.5.4 Politics and climate; president Obama's 'organizing for action'

It's clear that belief in the reality of man-made climate change is coloured by the degree of support a person has towards the political actions that would be deemed to be necessary – if the hypothesis were true. This has created a clear division between the left and the right of politics on this issue, especially in the USA where strong polarisation has taken place. The division between the recent left-wing administration of Barack Obama and the newly-installed right wing administration of Donald Trump is obvious on climate. Effectively, a government run for the last 8 years by president Obama, on the website he started (OFA, 2017), run by the organisation he started and is still the patron of, namely; 'Organizing for Action' (OFA). President Obama certainly had climate change action as a main priority during his term. Its home page states boldly;

"FIND DENIERS"

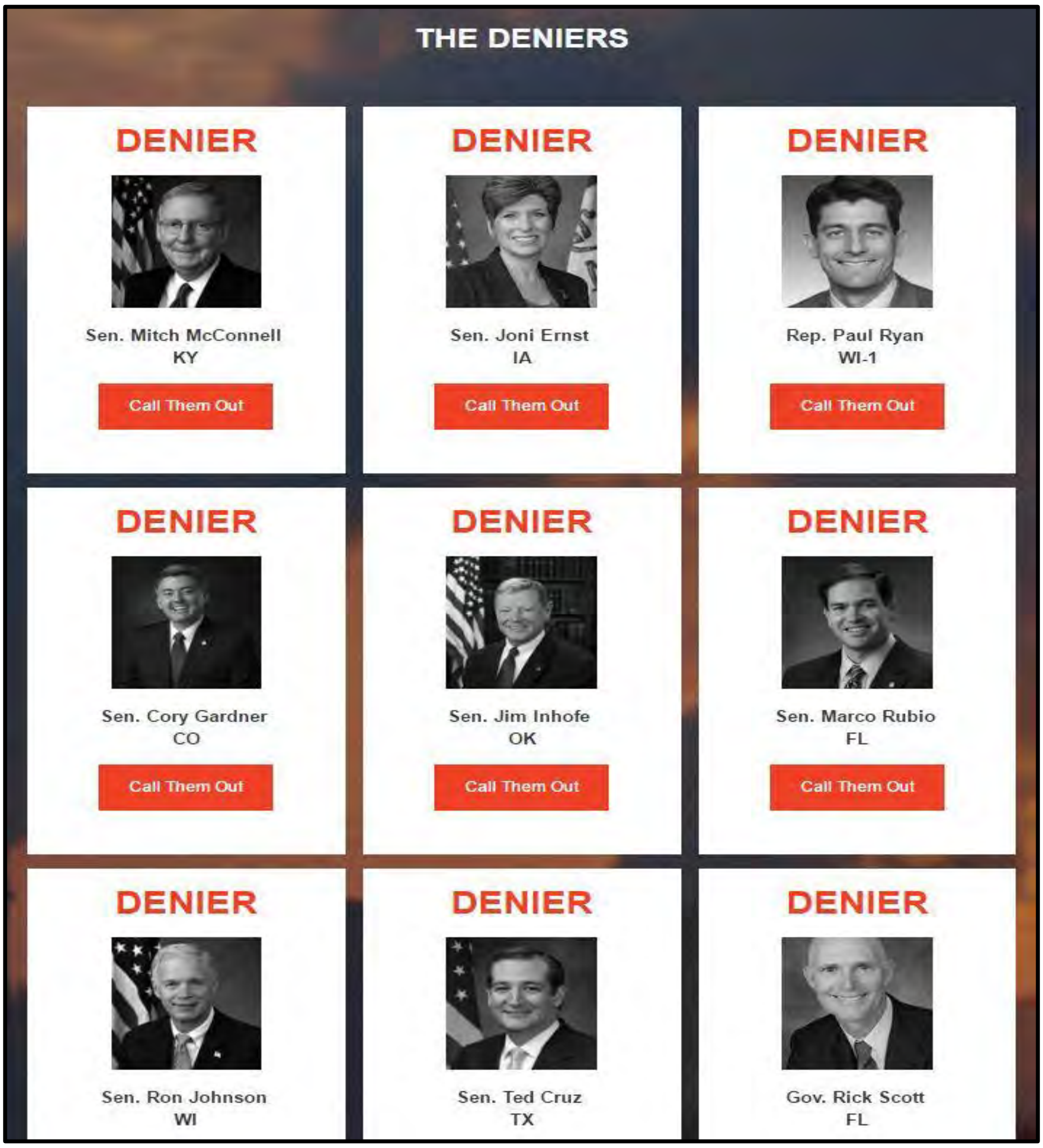


Figure 4.5 Obama's website and part of the long list of 'deniers' (OFA, 2017)

Any person's name can be typed in, and OFA will advise immediately whether that person is classified by them as a 'climate denier' or not. Below this, a long list appears (Figure 4.4) containing hundreds of photos of the people's current representatives in the U.S. congress – that is, those voted in democratically by the American people – and all of them on this hit list are described by a single word in red over their heads; 'DENIER' under the general heading of; 'THE DENIERS'.

A question needs to be asked here;

'Can unbiased science really come from government-funded and government-controlled science agencies, when the government itself is biased?'

4.1.5.5 The practice of labelling people who wish to debate science, 'deniers'

Labelling people in this way, and often taking this much further by putting their photograph on a website that the President of the United States is the instigator and the patron of and describing them by the single word 'DENIER' is a shocking escalation of what is really, and should remain, a scientific dispute. The word is a thinly-veiled reference to holocaust denial and is an obvious attempt to discredit and to silence any debate or dissent by intimidation. Indeed, those who run this site, including government officials right up to and including Barack Obama, the former president of the United States, have frequently asserted that;

"There is a consensus, the debate is settled" and
"Climate change is a fact" (OBama, 2014).

Of course, as all trained scientists know, the reality is that science is not done by consensus, and all scientific claims can be debated; there is in fact a very lively debate in the climate literature, and no science is ever completely settled (Crichton, 2003) (Hulme, 2009). Shutting down debate is a line of attack on science, on scientists, on the scientific method and on free speech in this field and this is unfortunately not just confined to the U.S.A.; it is widespread in Europe and in other Western countries.

4.1.5.6 Do most universities now actively prevent free speech?

Freedom of speech on certain subjects, such as gay marriage, Aboriginal child abuse, Islamic terrorism and climate change, has been under growing attack at universities in in the West. It has been noticeable in Australia over recent decades, with right-wing politicians repeatedly being shouted down and even assaulted when they try to speak at institutions of learning (ABC News, 2014). Students themselves are now having their free speech curtailed at some universities (Begg, 2016). This intolerance has now spread to the wider community; cartoonists cannot print a cartoon on these subjects without the fear of either verbal threats, physical attacks, or a lawsuit (Allan, 2016). Right wing commentators have been violently attacked in the street after speaking out on these subjects (SMH, 2017).

A recent study (Lesh, 2016) by the institute of public affairs (IPA) found that 33 of Australia's 42 universities had policies which 'substantially limited' free speech, and only one out of the 42 actually passed their free speech test. How likely is it that a problem will be solved, if debate on the subject is not allowed? Shouldn't Australian universities be the very places where accepted ideas are challenged, and scientific or other vigorous debate and a diversity of thought and opinion is encouraged?

4.1.5.7 Going much further; climate dissenters threatened with jail

In the U.S.A., there has also been a push among some democratic representatives led by Senator Whitehouse and some 'mainstream' climate scientists to not just silence opposing scientists and others, but to imprison them, specifically those whom they are now calling 'deniers'. Twenty scientists, led by Professor Kraft (New Scientist, 2016) of the University of Wisconsin want charges laid under an old racketeering law the racketeer influenced and corrupt organizations act (RICO). Incredibly, this idea was taken seriously by President Obama's attorney-general, Loretta Lynch, and she is reported as replying to a question on this by Senator Whitehouse on March 9th, 2016 by saying;

> *"This matter has been discussed. We have received information about it and have referred it to the FBI to consider whether or not it meets the criteria for which we could take action on". (CBS News, 2016).*

It appears that more than just free speech is under threat for people who have the temerity to demand evidence-based science and insist on scientific debate; personal safety and freedom itself may in danger. But some incensed climate activists want to take direct action against the scientists whose work shows that there is no real danger from anthropogenic CO_2 emissions, much further. Recently, (April, 2017) Professor John Christy and Professor Roy Spencer's office building at the university of Alabama was sprayed with gunfire; seven bullets hit the 4th floor, where John Christy's office is (Tennessee Star, 2017). Professor Christy is Alabama's state climatologist. The bullets were fired into the building soon after a ‘march for science’ climate activist rally passed near the building on Earth day, the 22nd April 2017. These scientists compile UAH MSU - one of the five global atmospheric temperature data sets upon which many rely for accurate information.

This attack follows on from comments by an Australian professor Richard Parncutt who, in 2012, called for ‘climate deniers’ to be ‘executed’ in a long-winded post on his own university’s public website. His full rant has since been removed but was archived by web-cite (Web-Cite. 2012); Parncutt still retains his university position. Political terrorism by a Burnie Sanders supporter, who specifically targeted republicans (some of whom are listed as ‘deniers’ on Obama’s OFA list) erupted on June 14th, 2017, leaving one dead and four others shot (CNN, 2017b). Majority republican whip Steve Scalise was critically injured.

4.1.5.8 Pseudo-science taking over society; it has happened before

Branches of science have become politicised before, making them in effect pseudo-science, both in the Soviet Union with Lysenkoism (Graham, 1971) and in the West with eugenics (Stepan, 1991). Both were propelled by faked data, destroyed any presented counter-evidence and were pushed along by political propaganda emanating from the very top of the government. Advocates of these ideas were favoured with government funding, promotion and awards. Objectors were called ‘fascists’ and denounced, discredited, demoted and jailed, some were executed. Perhaps most surprising to those who live in the west and think that this is an enlightened society, is just how fast scientists, politicians and the media in the West fell into line, and under the spell of eugenics (Lombardo, 2011). Forced sterilisation first took place in Indiana in 1907 and was quickly followed by 30 other states in the U.S.A. and soon, the beliefs and practice of eugenics had spread to a dozen other countries, including to Nazi Germany, where 10 million people who were deemed to be ‘undesirable’, died later in gas chambers. Keeping foreigners deemed to be ‘unfit to breed’ out of the country was a priority in many countries and euthanasia was quietly practiced by many doctors on those who were subjects of some of the countries.

Under the pseudo-science of Lysenkoism, which started in the Soviet Union in 1928 (Graham, 1971), millions starved to death; thousands of scientists who opposed the ideas were jailed, and many of these were executed. Lysenko’s ideas finally died out in the 1960’s and he was discredited. The belief in eugenics lasted much longer in the West, starting in the 1880’s. Although generally discredited by 1945, many individuals in positions of power, retained a belief in this pseudo-science for much longer.

An example is Stanford-trained Professor John Holdren, a long-time believer in eugenics (Ehrlich et al., 1977) and population control through forced sterilisations and abortions, was the U.S. President's principal science advisor (Harvard, 2017) until the 20th January 2017; when, with 8 years of service, Holdren became the longest-serving science advisor in U.S. history. The U.S. government was then still providing funding for sterilisations and abortions overseas, but especially among the poor of Africa, right up until the 23rd January 2017 when the practice was stopped by an executive order of the new president (The Hill, 2017), this was done by re-instating the 'Mexico City' policy of Ronald Reagan. Holdren was also a key advisor to president Obama on climate change – and action on climate change right until he left office in 2017. Holdren is now encouraging other government-employed scientists to become part-time activists (Quartz Media, 2017).

4.1.6 The Australian government and climate action

4.1.6.1 What is "carbon pollution"?

Several high-ranking politicians and at least two recent Australian prime ministers have referred to 'carbon pollution'; just what is meant by this? They are referring to the emission of certain gases, which result from human activity such as CO_2, CH_4 and other GHG which contain the element carbon. This appears to be an incorrect use of the word 'pollution', at least in the case of CO_2, which is not poisonous, and is necessary for life, being plant food (S. B. Idso & Idso, 2001). Unless it is scientifically proven that carbon dioxide harms the environment, it is clearly no more a pollutant than oxygen or water is.

4.1.6.2 What significant actions are the international community taking?

The most recent climate meeting organised by the UNFCCC was the COP21 in Paris, December 2015, which was attended by 195 countries, and 193 of these signed the agreement (Rogelj et al., 2016). The aim of the Paris agreement, according its article 2, is to reduce overall GHG emissions so that it should be possible to;

> *"Hold the increase in the global average temperature to well below 2 °C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5 °C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change" (Rogelj et al., 2016).*

Each individual country is asked to make what contributions it can to the desired emissions reductions to achieve the 2030 target of no more than a 2 °C rise above pre-industrial levels. What might be considered to be flaws in the agreement by some, is that there is no across the board cuts nor any mandated emissions cuts. For example, developing countries are thought to be a 'special case' by the UN. China, which is by far the planet's biggest man-made GHG emitter already, with emissions that are more than double those of the next biggest emitter (the USA) China is not expected to reduce its GHG emissions, in fact they are slated to grow substantially until at least 2030. In relation to VAM, China's emissions, already higher than all other countries combined, are expected to increase substantially by 2020 (Yusuf et al., 2012).

4.1.7 The Australian government has mandated action on climate

If the average of the IPCC's temperature projections for the year 2030 is taken to be accurate, then a business as usual course will result in a global temperature which is +0.5 °C higher than current levels (Figure 4.5) (Team et al., 2014).

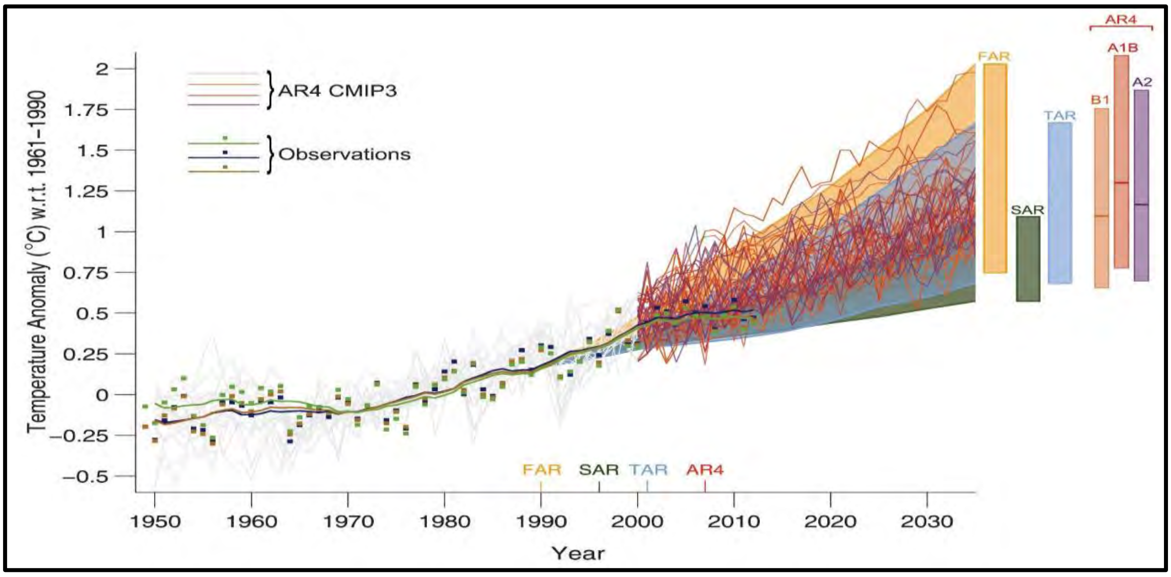


Figure 4.6 IPCC temperature scenarios to 2030 vs actual to 2014 (Team et al., 2014)

Total global emissions 2014 – 2030 on a BAU basis will be ~720Gt, of which the IPCC says 50% will remain in the atmosphere. This essentially mean that ~360Gt will cause a global temperature rise of ~0.5°C. Australia is planning to cut its emissions by 5% below 2005 levels by 2020 and 27% below 2005 levels by 2030; this represents an emissions reduction by 2030 of ~ 1,452Mt CO_2-e. This amount is 0.4% of net global emissions by 2030, which will therefore, according to the IPCC, reduce the global temperature rise by 0.4% thus;

$$0.4\% \text{ of } 0.5°C = 0.002°C$$

The cost for Australia to cut global temperatures in 2030 by the unmeasurable amount of 0.002°C is now calculated, and totals at least A$55.55 billion (Table 4.1);

Table 4.1 The estimated cost of Australia's emissions cuts to 2030

Action taken	Billions A$
Emissions reduction fund to 2020	2.55
Cost of solar P.V. rooftop systems	5.00
Innovative renewable technologies	1.00
Cost of carbon tax 2012-2014	17.00
Wind subsidies (cost of RET)	28.00
Other costs	2.00
Total costs	55.55

This represent an average mitigation cost of ~A$26 t/$CO_2$-e which is in line with, or below the estimates from the Warburton and other reports (Wharburton, Fisher, & Zema, 2014) (Minerals Council, 2013). Note that it would never be known if any of this spending was successful at reducing warming. Firstly, for Australia, the 0.002°C is currently not measurable; secondly, if the entire 0.5°C were to be hypothetically averted by global emissions cuts, this also could not be known, since the warming amount nominally attributed to humanity has never been satisfactorily separated from natural variability. If all of the planned 2030 Paris global emissions cuts were to be mitigated at the Australian cost rate, the total would be A$13.7 trillion, or about 15% of global GDP.

As can be seen from the overview of the state of the science of climate change, the situation cannot in any way be described as 'settled science'; the whole field is in flux and is a work in progress. Nevertheless, the Australian government has signed the Paris agreement and is committed to spending tens of billions of dollars more of taxpayer's money to achieve the mandated emissions cuts; this is the reality that coal miners, scientists and engineers across the country must deal with. From the perspective of these parties, their role should be to achieve these mandated cutes in the most cost-effective way possible, and with the least impact on the public and economy. Part of this involves submitting unbiased advice to decision-makers about the areas of industry which can make safe and cost-effective emission cuts and pointing out that cutting emissions at costs of A$100+ per t/$CO_2$-e as many state governments are now doing makes no economic sense. Of course, in the end, it's not government officials or companies who pay to cut emissions – it's the public who always will eventually bear the cost.

4.1.7.1 Australian public are less willing to pay to 'stop' global warming

One important ingredient in any action which targets an emissions reduction is cost. Cost here is measured in Australian dollars per tonne of CO_2 equivalent which has been mitigated. This is very important because these costs are always eventually borne by the public in one way or another, and the fact is that the Australian public is becoming less and less willing to pay for climate change action over time (Figure 4.6), as consecutive polls conducted by the Lowy institute show (Oliver, 2015). Currently, over 40% are not willing to spend even one dollar, and a further 12% are only ready to spend A$2 per week. This brings the price of climate action (to reduce emissions cost-effectively) into sharp focus; and cost for a given emissions saving, is where this research can be of the greatest assistance and benefit.

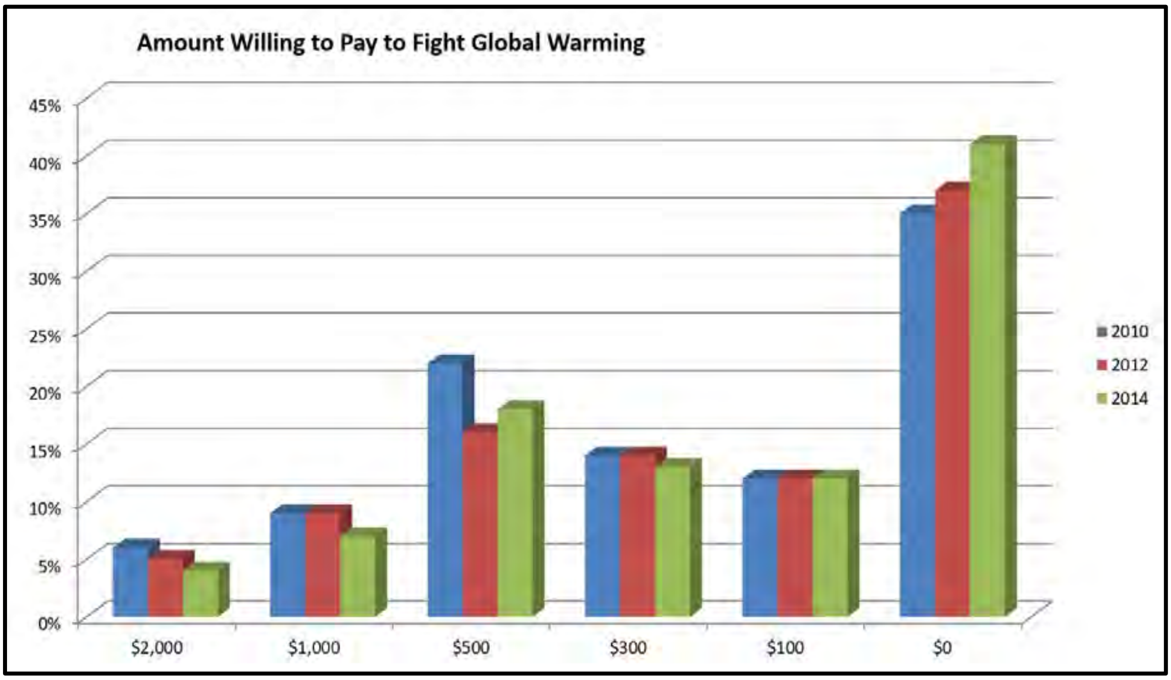


Figure 4.7 Australians are less willing to pay to stop global warming (Oliver, 2015)

4.1.7.2 What actions is Australia taking?

Australia's 2020 emissions target is 5% below 2005 levels by 2020 under previous UNFCCC agreements, but the country is now a signatory to the Paris climate agreement. Australia's new target under the Paris agreement is for emissions to be 26-28% below 2005 levels by 2030. Currently, the government is on target (Table 4.2) to achieve that level of emissions reductions. The main federal programs which are being implemented to achieve these significant cuts are the government's direct-action plan, the renewable energy target (RET), new building performance standards and the emissions reduction fund (Department of the environment, 2016).

Table 4.2 Australia's 2005 base level and its future emissions targets

Australia's Emissions in 2005	612 Mt/CO_2-e
Australia's Emissions in 2020	533 Mt/CO_2-e
Australia's Emissions in 2030	441 - 453 Mt/CO_2-e

4.1.7.3 What effect will those emissions cuts have, and at what cost?

The effect by 2100 on the projected rates of global warming, (given that the average IPCC scenario of an ECS of 3°C is correct) by these cuts would be perhaps 0.001°C averted, and so not physically measurable. In fact, if Australia cut its emissions now by 100% and continued this until the year 2100, the warming averted would be below 0.03°C, and still would not be measurable. The cost of achieving the 2020 target is conservatively estimated at A$55 billion (Table 4.1), which includes the RET (Wharburton et al., 2014). The current price of renewable energy certificates is A$52/MWh, and currently this costs consumers A$2.5 billion per year (about A$300/family/year). Mandatory renewable generation, job losses due to high energy costs, the direct-action plan, and various state schemes such as wind and solar generation subsidies can be added to the total, which altogether results in very high societal costs. Cutting global temperatures at these relative costs by the 1°C that is said to be required to stay below the COP21 2°C target, would require an expenditure globally of A$500 Trillion, which is ~A$6 Trillion per year out of the present annual global turnover of A$140 Trillion. This represents an annual expenditure of more than 4% of global GDP.

5 Chapter 5: Development of New Mitigation Methods

5.1 A Natural Progression

This work represents a natural progression from previous work; a master's thesis, completed in 2009, which was partly on the estimation of VAM gas emissions from a colliery in Queensland. It was always the intention to progress to a PhD on quantifying a non-gas drainage VAM mitigation method when the opportunity arose. A ventilation officer has full responsibility of the day-to-day operation of the ventilation system; and in a new role in NSW, and with the permission of management, the opportunity was taken to put this method of mitigation that had been under consideration for some time, into practice. A twelve-month six-measure VAM gas mitigation trial was undertaken in the period July 2012 to June 2013. All the notes and raw data collected from the various mitigation works that were undertaken was kept until the commencement of a PhD candidature in February 2014. The raw data was then collated, modelled and reworked; it now forms an integral part of this thesis and is presented in this chapter. The results of the trial were also written up as papers and were published in the peer-reviewed technical literature (R. I. Holmes, 2016b), (R. Holmes, 2016a) and reported in seminars and conferences. Previously, four identified methodologies have been employed in collieries which have the effect of reducing fugitive emissions involving VAM. These four methane gas mitigation methods for collieries have been detailed previously (Yusuf et al., 2012).

1. Degasification by gas wells
2. Enhanced degasification by gas wells
3. Oxidation of VAM by thermal or catalytic conversion
4. Flow reversal (regenerative heat exchange) can cope with low %CH_4

Only the first has seen widespread use across many collieries to date. Another method of VAM mitigation (albeit using six existing tried and tested gas control mining practices) is herein quantified & costed, and so represents a fifth VAM mitigation method;

5. Prevent methane from becoming VAM by various non-gas drainage means

5.2 The 12-month trial and the measured reduction in VAM

During a recent VAM mitigation trial from July 2012 to June 2013, a VAM mitigation method involving six different measures was trialled to quantify how much VAM gas could be prevented from being created by using them. All six measures were put into practice at a multi seam longwall mine in the Hunter Valley, Australia. The mine has an extractive-fan and a ‘U’ ventilation arrangement and emits approximately 500,000 t/CO_2-e in VAM emissions annually. These extra VAM mitigation measures are not normally put in place at collieries, because once safety and statutory compliance gas levels have been attained that historically has been considered to be sufficient. Residual fugitive emissions are not considered. The six extra measures of VAM mitigation put into place were;

- identify and stop all seal leaks
- seal off roadways in the mine where access was no longer essential
- install 35 kPa stoppings in front of old 140 kPa seals
- change seal design from shotcrete to mine plaster
- reduce leaks from old sealed goafs by pressure balancing
- use pressure differentials and buoyancy to move CH_4 to storage in old goaf voids

Use was also made of a surface gas drainage plant which tapped into the goaf through pre-drilled vertical holes at 400m intervals. Here, ‘active monitoring’ to determine fine course adjustments to the CH_4 drainage system to reduce CH_4 ingress into the mine airstream was practiced. Although some large extra reductions in VAM gas were noted, no claim was made for mitigation above normal operating conditions for the gas drainage plant has been made here, because the CH_4 destruction flares necessary for successfully quantifying this measure were not installed until after the trial period had ended. Under the right circumstances, this would have comprised a seventh measure.

The emissions mitigated by each of the six measures were individually quantified and costed, and the total mitigation achieved during the trial period was 95,398 t/CO_2-e, at total cost of A$103,200 (R. Holmes, 2016a). (The mitigation achieved in CO_2-e has been revised slightly from that in the published material, due to a change in GPA for methane by the IPCC from 21 to 25.)

This represents an average mitigation cost of A$1.08 per t/$CO_2$-e. The A$103,200 mitigation cost for the 95,398 t/CO_2-e is comprised of estimates of the ventilation officer’s time, deputy’s time, consultants’ time and mineworker’s time to perform various duties including ventilation changes, seal remediation and estimated costs of the construction materials required for the various works. If the emissions had not been prevented, there would have been a carbon price applicable at the time of A$23/t CO_2-e which would have totalled 95,398 x A$23 = A$2,194,154 over the 12 months. Thus, a net cash saving to the mine because of the trial of A$2,194,154 - A$103,200 = A$2,090,954 was achieved as well as the environmental benefits of the prevented emissions (Table 5.1). VAM abatement was calculated to be equivalent to 188.9 l/s for the next 12-month period (Table 5.2). Note that in all calculations in this work, turbulent leakage is assumed; this means that the leakage formula $Q^2 = P/R$ is used in all cases.

Table 5.1 Cost-benefit analysis of the six-measure trial; over a 1-year projection

VAM mitigation measure	Cost A$	CO_2-e t/yr	Mitigation A$ cost /t A$/$CO_2$-e/t	If emitted; cost is A$23/t/yr
Stop leaking seals	4,200	8,640	0.48	198,720
Seal off roadway	80,000	67,100	1.19	1,543,300
Install 35 kPa	5,000	1,000	5.00	23,000
New seals	1,000	316	3.16	7,268
Pressure balancing	7,000	16,070	0.43	369,610
Increase CH_4% goafs	6,000	2,272	2.64	52,256
Totals	A$103,200	95,398*	A$1.08 average	A$2,194,154

Table 5.2 Total VAM abatement achieved in l/s

Measure	VAM abatement l/s
1	16.8
2	132.8
3	2.5
4	0.6
5	31.8
6	4.4
Total	188.9

**Note that a mitigation of 95,398 t/CO_2-e is the equivalent in emissions savings as taking 20,000 cars off the road for 1 year. (EPA Australia).*

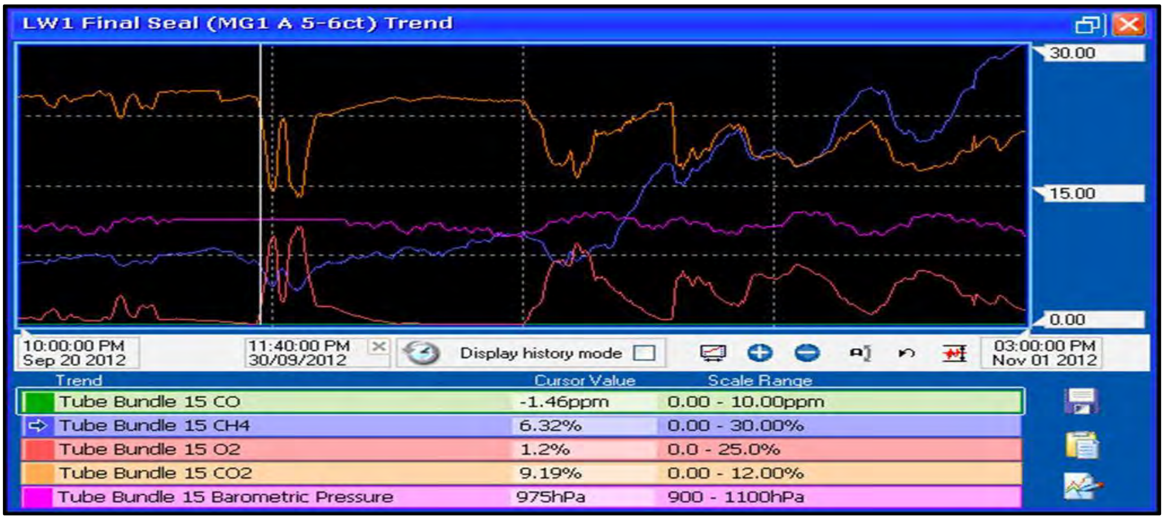


Figure 5.1 CH_4 (blue line) in the LW1 Pikes Gully seam increases from 6% to 30%

The mitigation achieved of 95,398 t/CO_2-e in one year was the mine's 'low hanging fruit'. Because collieries have not invested in the prevention of VAM gas purely for environmental reasons, most collieries can be expected to have these low-cost mitigation possibilities. Further cuts to fugitive emissions are possible, by using a more stringent application of the same measures, and were estimated to be achievable at a still very competitive cost of A$2-$4/t for a further ~50,000 t/CO_2-e/yr. Increasing storage of CH_4 in old goaf voids was one measure used; CH_4 concentration increased from 6% to 30% in the old goaf void of LW1 (Figure 5.1) and then to 65%. The main return of the PG seam was monitored throughout the mitigation trial period, and the changes in VAM flow recorded (Figure 5.2).

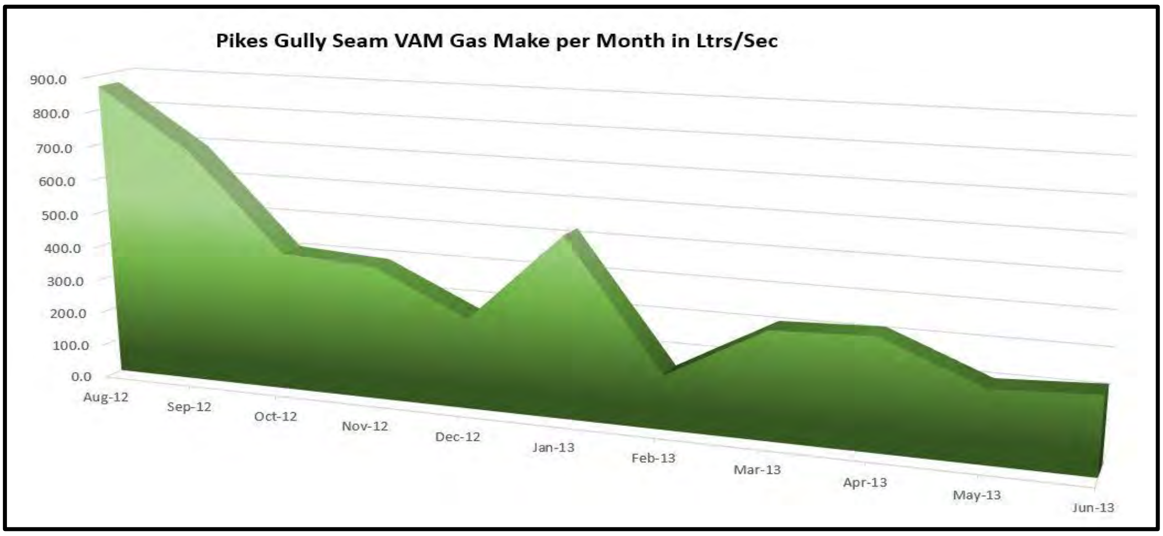


Figure 5.2 VAM as measured in the main returns of the PG seam during the trial*

**note; not all the reduction in VAM gas seen here is due to the mitigation efforts of the trial*

5.3 Mitigation claims are prudent

It will be noted that in all the measures, mitigation is calculated and claimed only for the subsequent year. What has dictated this is an abundance of caution, to ensure that no mitigation over-estimate can occur. However, a more accurate time-frame that should be included to better estimate the true emissions savings achieved by the works, may well be a period of three years, - which if adopted would in effect almost triple the savings estimates, and reduce the mitigation cost per tonne. Why three years? This comes down to the average expected remaining mine life from any point in time, coupled with a combination of an expected deterioration in the seals and other controls which are retaining the gas in place and the effects of the many ventilation and other changes which happen almost daily in an operating colliery; these effects tend to reduce projected mitigation totals over time.

5.4 Trial results tested by modelling VAM flow at two other mines

These two best results from the 12-month mitigation trial are tested by taking measurements from key locations in two other Australian mines and modelling them for comparison. In this way, the best two measures (as determined by the trial results) are to be either validated or invalidated for their applicability to wider use.

Pre-curser work to this present thesis was carried out during a July 2012 to June 2013 mitigation trial at a Hunter Valley longwall colliery, which involved a method of GHG mitigation for a safe and cost-effective reduction in fugitive VAM emissions. This method included six different measures, all of which were individually quantified for effectiveness and cost. The most successful two measures of the six are to be brought forward for modelling assessment using data from two other working long-wall collieries. The two measures to be assessed are the second and the fifth of the six, respectively;

Measure 2) The seal-up of an unnecessary mine roadway
Measure 5) The pressure balancing of a sealed panel

These mitigated 70% and 17% respectively of the total fugitive emissions mitigated in the 12-month trial; comprising 87% of the total mitigation achieved during the trial. The modelling of these two measures will be detailed in chapter six.

5.5 Results detail of the six measures

5.5.1 Identify and stop seal leaks from seals

Example: A small leak was discovered in an old seal, the leak was measured by surveying the roadway on either side of the seal for airflow and percentage of CH_4, and calculated to emit an average of 700ml per second of CH_4. To simplify matters, no allowance is made in any calculation for pressure or CH_4 density changes due to movement of CH_4 in a vertical direction, which in any case are small because of the shallow depth of the workings in question.

Emissions in CO_2-e are given by:

Ideal Gas Law; Density = PM/RT (22)
P = mine pressure = 0.978 atm
M = molar mass = 16.042g/mol
R = Gas constant = 0.82057 L atm mol^-1K^-1

T = mine temp in Kelvin = 298.15K
GWP from the IPCC's AR4 = 25
Mine density CH_4 = 0.978 atm x 16.042 g/mol / (0.082057 Latmmol^-1K^-1 x 298.15 K) = 0.641 gm/l
Litre/700ml = 1.4
Leak is therefore 0.641 gm every 1.4 sec
There are 31,550,000 seconds in a year/1.4 = 22,500,000
22,500,000 x 0.641 gm = 14.4 t/CH_4
CH_4 make x GWP = CO_2-e emissions
14.4 x 25 = 360 t/CO_2-e/yr

A small leak of this size is difficult to detect without regular and accurate measurements or leak tests taken very near the seal; these are not routinely done. The daily diurnal pressure changes also mean that the leak may often stop or even reverse, making it all but undetectable at those times.

Leaks like this are very common in old seals around sealed up panels; and old sealed panels often have 50 or more seals. Finding and plugging this small leak is the equivalent in greenhouse emissions saved, to taking 60 cars off the road. The equivalent of 24 leaks of this size were detected in surveys, (totalling a VAM reduction of 16.8 l/s CH_4) and all were quickly and satisfactorily plugged and sealed using portable silent seal products, cost calculation is in Table 5.3.

Table 5.3 Cost calculation for stopping leaky seals

Deputy and ventilation officer's monitoring time 20 hours	$2,000
Mineworkers time applying product 15 hours	$1,000
Silent seal x 2	$1,200
Total	$4,200

5.5.2 Seal off unnecessary roadways in the mine

The single-entry back road of the upper PG (Pikes Gully) seam was sealed up on the 29th September 2012; because this 5km of roadway was already planned to be sealed, the associated emissions savings were not counted as part of this study. However, other roadways were not planned to be sealed off in the normal course of events; namely, MG9 and the back road of LW8 (Figure 5.3).

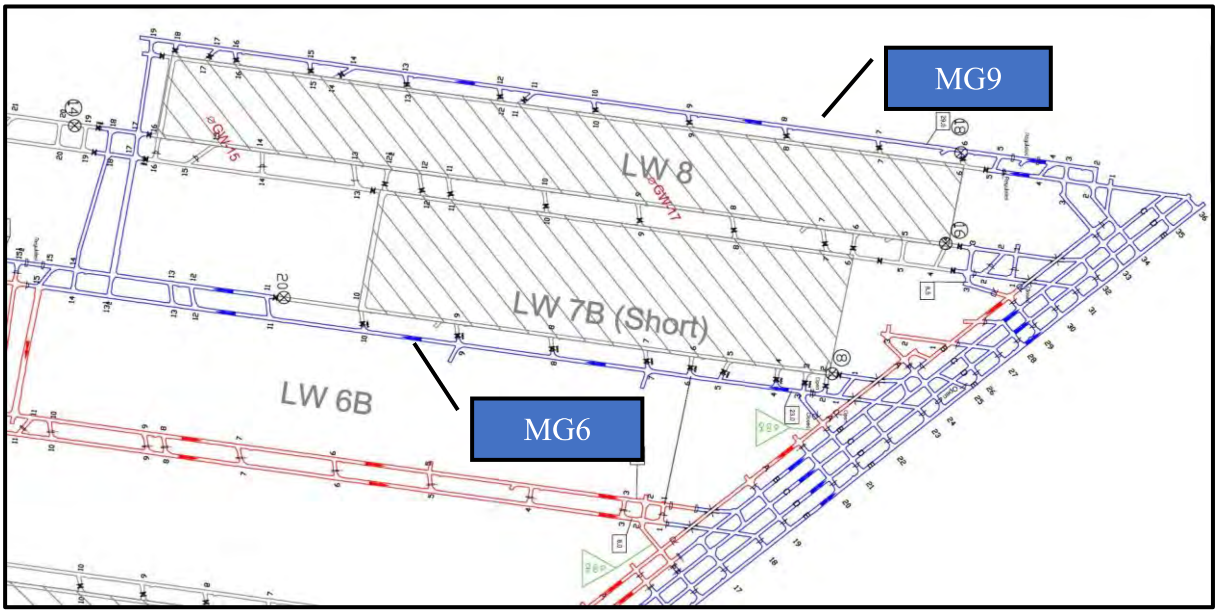


Figure 5.3 Hunter Valley colliery map detail of LW8 and LW7B

These roadways were known at the mine to be a particular source of CH_4 leaks.
This was mainly due to;

- Old-style shotcrete seals, which were unsatisfactory
- Wooden cribs which shrink as they dry out, causing them to fail to support the roof properly
- Geotechnical issues caused by the narrow width of the MG9 pillars
- Spalling ribs in the various cut-throughs which caused leaks

Although there had been no plan to seal off these roadways, the cost of the above maintenance issues coupled with the related emissions costs incurred to the mine in terms of the then-existing carbon price, made the decision to seal it off possible. Prior to the seal-up of MG9 and the back road of LW8, the airflow required to ventilate them was 29.5 m³/s; this was more than 10% of the entire mine airflow. Even then, the in-bye end of the roadway could exceed 1% CH_4 during rapid diurnal falls in atmospheric pressure, (this represents a CH_4 make of 300 l/s) often occurring at 4pm and 4am; thus, preventing machinery access at those times. Several spot CH_4 measurements and surveys of the roadway were made by the deputies and the ventilation officer respectively, and the average intake and exit CH_4 levels just prior to seal-up were determined to be;

Intake 5-6 cut-through (henceforth c/t) A heading (hdg) MG9	0.05% CH_4
Backroad LW8	= 0.50% CH_4
MG9 CH_4	= 0.45% of 29.5 m³/s
Average make CH_4	= 132.75 l/s

Using above calculation;

0.641 gm/litre x 132.75 = 85.1 gm/s
31,550,000sec x 85.1 = 2,684 t/CH_4/yr
2,684 x 25 GWP = 6.7100 x 10^4 t/CO_2-e/yr

The annualised cost of these emissions to the mine at the time was 67,100 x A$23 = A$1,543,300. A decision was made to seal these two roadways and to inertise them by using CH_4 from the LW8 sealed goaf.

Calculated time to inertise the 1,800m roadway;

Volume of roadway; 1,800m x 14.5 = 26,100 m^3

CH_4 required to inertise roadway; 26,100 x 0.15 = 3,915 m^3

Estimated CH_4 make of MG9 seals; from12 noon to 6pm = >300 l/s

Estimated time to reach >15% CH_4; 3,915/0.3 = 13,050 sec (3.6 hours)

- Sealing was undertaken on a falling barometer between 11 am and 5pm
- The out-bye end of MG9 will be on –ve 400Pa return pressure causing the seals to breathe out
- LW8 contains 95% CH_4; this will be used to inertise MG9 and the LW8 back road
- The 4” inertisation pipeline which passes through the seals will be opened on personnel exit
- Up to 20,000 m^3 of CH_4 will be stored in this roadway
- Approximate volume of CH_4 in LW8 goaf is 150,000 m^3
- This stored CH_4 can be tapped from the surface and used for power generation at a later time
- The emissions saved are annualised for one year, even though these roadways in the normal course of events would have been in use for much longer.

Table 5.4 Cost calculation to seal a roadway up

Deputy and ventilation officer’s time 100 hours	$10,000
Risk assessment	$12,000
Seal-up doors x 2	$11,000
Pipework and clearing roadway	$20,000
Ventilation change & seal-up works	$25,000
Monitoring costs	$2,000
Total	$80,000

5.5.3 Install 35 kPa stoppings in front of old 140 kPa seals

To use the single-heading of MG6 as a long-wall main-gate intake and as a belt road, called for innovative thinking at the mine (Figure 5.3). This situation was brought about because of out-of-sequence panel mining, caused by delays in surface environmental works associated with the re-location of a creek. The installation of the extra 35 kPa stoppings was done along the single heading in MG6 to increase seal resistance enough to keep CH_4 ingress from sealed panel LW7B into MG6 to within the statutory limit. Because this roadway was later to be the main-gate (intake) for the extraction of LW6B, these prevention works were important because the statutory limit is just 0.25% CH_4 on long-wall intakes in NSW. Measurements of pressure and CH_4 were done along MG6 and its seals associated with LW7B in order to quantify CH_4 make and any likely problems which may occur due to this leakage into the main-gate during the extraction of LW6B.

The installation of 35 kPa mine plaster barrier stoppings in front of the existing 140 kPa seals was decided on in at a risk assessment for the mining of LW6B, in spite of the excellent condition of the seals. The decision was based on two factors, prudence; and the modelled and calculated extra leakage expected from these seals as they were put under more differential pressure due to the extra airflows needed for servicing a production main-gate. A further control would be a 0.25% CH_4 detector in the main-gate, which would trip the power to the long-wall if exceeded. Other contingencies were planned for in the risk assessment, such as an application for an exemption to the 0.25% intake rule; it was hoped permission to allow 0.5% for this panel could be gained from the inspector. Other contingencies which were planned for were a provision to draw off the CH_4 in between the barrier seals; pipework for this was to be pre-installed and excess CH_4 was to be directed into the returns. However, it was hoped that in practice, neither of these contingencies would be required.

Pressure drop down MG6 now are given by:

Find Atkinson's resistance of the current situation first, using;

$$\text{Resistance} = KL\,Per/A^3 \qquad (23)$$

K = Friction Factor = 0.009 kg/ m^3 (after McPherson)

L = Roadway Length = 1,000m

Per = Roadway Perimeter = 16.4m (roadway 5.4m wide, 2.8m high)

A = Roadway Area = 15.1 m^2

$$R = KL\,Per/A^3$$
$$= 0.009 \times 1{,}000 \times 16.4/15.1^3$$
$$= 0.0428\ Ns^2/m^8$$

Find pressure drop, P;

$$P = RQ^2 \qquad (24)$$
$$= 0.0428 \times 23.0^2$$
$$= 22.64\ Pa$$

Projected pressure drop down MG6 are given by;

K = Friction Factor = 0.011 kg/ m^3 (after McPherson)
L = Roadway Length = 1,000m (at start)
Per = Roadway Perimeter = 16.4m (roadway 5.4m wide, 2.8m high)
A = Roadway Area = 15.1 m^2
R = KL Per/A^3
  = 0.011 x 1,000 x 16.4/15.1^3
  = 0.0524 Ns^2/m^8
Find pressure drop, P;
P = RQ^2
  = 0.0524 x 60.0^2
  = 188.64 Pa

Airflows along MG6 were expected to rise from the current 23.0 m^3/s to 60.0 m^3/s during production; a conveyor belt is also to be installed in MG6; because of this, vehicle access is to be largely via B hdg in the tailgate. The pressure drop down the length of the roadway was calculated to increase from 22.64 Pa to188.64 Pa. This would increase the pressure differential down the length of sealed panel 7B by the difference between 2/3rds of these numbers (given that panel 7B is two-thirds the length of MG6).
This increase in differential pressure along the length of the sealed goaf 7B, can then be quantified as;

2/3rds of 22.6 Pa	= 14.9 Pa and
2/3rds of 188.6 Pa	= 124.5 Pa respectively.

The pressure differential along the sealed panel length therefore is projected to increase substantially from a negligible 14.9 Pa to 124.5 Pa. This would be expected to cause the in-bye seals to leak more by adding to the already substantial (approx. ±150 Pa) diurnal changes during their median daily lows at around 4pm and 4am. The average diurnal change of ±150 Pa, added to the pressure fall during production along the length of the sealed panel would be 124.4 + 150 Pa = 274.4 Pa.

However, because any passing storm will cause a barometer to fall in excess of the average diurnal change, prudence in planning demands that a factor of safety is used here before any pressure level in the determination of the seal resistance which is required to prevent excessive CH_4 leakage into MG6 are calculated. Because of the very real concern over the potentially high costs associated with any production shutdown due to CH_4 ingress, a factor of safety of 1.5 was decided on, hence a maximum differential of; 274.4 x 1.5 = 412 Pa was to be used in the CH_4 flow calculations;

Flow	= 60 m^3/s
Max CH_4 concentration allowed	= 0.25%
CH_4 concentration on panel intake measured at	= 0.05%
Leakage allowed is therefore	= 0.20%
	= 60 x 0.002
	= 0.12 m^3/s
Allow for the CH_4 concentration being 90%	= 0.14 m^3/s

At LW6 start-up, nine seals in MG6 would need to be included in the calculations (In B hdg and 3cut-through (henceforth c/t), 4c/t, 5c/t, 6c/t, 7c/t, 8c/t, 9c/t, 10c/t and in A hdg 10-11c/t).

Since; $Rt = P/Q^2$ (25)

Then; $= 412/0.14^2$

Total resistance; $= 21,000\ Ns^2/m^8$

Since; $\frac{1}{\sqrt{Rt}} = \frac{1}{\sqrt{R3c/t}} + \frac{1}{\sqrt{R4c/t}} \ldots\ldots \frac{1}{\sqrt{R10-11c/t}}$ (26)

And if; R3c/t = R4c/t = R5c/t = R6c/t = R7c/t = R8c/t = R9c/t = R10c/t = R10 -11c/ t (27)

Then; $\frac{1}{\sqrt{Rt}} = \frac{1}{\sqrt{21,000}} = 0.0069$

And; 0.0069 / 9 = 0.00077

And; $0.00077 = \frac{1}{\sqrt{R\ any\ seal}}$

Then; R any seal = 1.68 x 10^6 Ns^2/m^8

The seals in each cut-throughs therefore need to achieve a resistance of ~1.7 x 10^6 Ns^2/m^8 to satisfy the specified CH_4 leakage restrictions into MG6. This proved to be achievable, leakage measurements showed that each set of seals reached 3.5 x 10^6 Ns^2/m^8. To reach this rating, the 140 kPa seals were sprayed over again, and up to 4m of rib and roof was also sprayed to a depth of 50mm. Then a second barrier seal of 35 kPa rating was installed 4m in front of that seal, and again, the roof and ribs sprayed out to 4m and to a 50mm depth. Tube bundle and local monitoring pipes were installed, along with a 200mm CH_4 drainage line through each 35 kPa stopping, and running to the main returns. The CH_4 drainage line was to be used in the unlikely event that leakage through the seals into MG6 caused production stoppages.

Methods of leakage measurement through coal mine seals has been outlined by Schatzel et al (Schatzel, Krog, Mazzella, Hollerich, & Rubinstein, 2015). The installation of the 35 kPa stoppings and the over-spraying resulted in some CH_4 leak reductions during the time-frame of this study, however most of the savings would have occurred after this study ended in June 2013; the reason is because the projected increase in airflow and hence the higher-pressure differential did not happen until after that. Therefore, an estimated pro-rata emissions savings and costs have been applied in this case.

Table 5.5 Cost calculation to install 35 kPa stoppings

Deputy and ventilation officer's time 10 hours	$1,000
35 kPa seal installation (part cost)	$4,000
Total	$5,000

5.5.4 Change seal design from shotcrete to mine plaster

Old-style 140 kPa shotcrete seals were being installed at the mine. These were found to be unsatisfactory form several points of view;

- frequently became leaky when roof, ribs or floor moved because of their rigidity and so required constant maintenance
- many leaks appearing on the roof-line or under through-seal pipework due to slumping of the concrete on installation adding to VAM gas and emissions
- costly and time-consuming to install
- no new-seal specific documented inspections carried out after installation
- single-tube roof monitoring arrangement unsatisfactory
- 140 kPa seal made of different materials to 35 kPa stoppings, requiring separate stocks of materials
- issues with safety because of the design re; materials handling
- long-time of installation causing unnecessary risks to workers i.e.; exposure to goaf and its Gases
- use of outdated wooden cribs, issues are; flammable materials, slow installation, materials handling issues, lack of ability to create rapid and positive roof support when needed, wood shrinkage issues causing failure to support roof over time, lack of continuous support causing rib spalling and leaks

A new seal design was implemented. The new seals are 140 kPa and made from high strength water resistant mine plaster (HSWR). The old wooden cribs were replaced by quick to install adjustable 40 tonne roc-props. The single roof-top copper sample pipe was replaced with 3 x pvc sample tubes, set at different heights behind the seal; the "traffic light" standard of red, yellow and green sample tubes. A new seal inspection regimen was implemented to assess and record the installation standard. The HSWR mine plaster seals were superior in almost every respect to the old shotcrete/single sample point/wooden crib arrangement which was in place.

The old seals would commonly have leaks straight after installation, typically of 5-10 millilitre/s. With time, the cribs would shrink and fail to support the roof both behind the seal and in front of it. The concrete would flake and decay, the bottom became affected by standing water; the roofline would separate from the seal top, movement in the ribs would cause spalling and more leaks. Constant inspections and repair works were necessary. Due to constraints on the deputy's time, often only the leakiest seals were noted and attended to. Detection of lesser problems and action on them was often left to the ventilation officer, working with one of the out-bye undermanager's. Costs here were minimal; in fact, the new seal standard saved the mine money.

Quantifying the effect on VAM of the switch to HSWR seals is tricky, because due to the expense, they were installed only as required during the normal running of the mine, and were not primarily installed for the specific purpose of controlling emissions. Their superior resilience, rapidity of installation, flexibility, lack of slumping, resistance to mine water and use of positive support like roc-props instead of cribs, all conspired to reduce both their initial production of VAM, and their production of this fugitive emission over time. These new seals are being installed at the rate of approximately 25 per panel, and one panel is mined on average every year. If it is assumed that the lowest likely average leak will be 50 millilitres/s, then the emissions saved after 1 year of steady replacement of the old leaky seals would be;

$50 \times 25 \times 0.5 \times 3.15 \times 10^7$ $= 1.9 \times 10^7$ litres saved

If the density of CH_4 is taken from calculation a above, = 0.641 gm/l

Savings: $0.641 \times 1.97 \times 10^7$ $= 1.264 \times 10^7$ gm

$= 12.64$ t/CH_4 x 25 GWP

$= 316$ t/CO_2-e/yr

Because the switch to a new seal design was not primarily done to reduce emissions, only a small part of any possible change-over cost is allowed here. In fact, a subsequent cost-benefit analysis has shown that the change-over to new seals had no net cost, and was revenue positive.

Table 5.6 New seals cost calculation

Deputy and ventilation officer's time (part cost)	\$500
Engineer's design drawings (part cost)	\$500
Total	\$1,000

5.5.5 Reduce leaks from old goafs by pressure balancing across panels

Leaks from old sealed panels in a long-wall coal mine still happen, even after the above strict regimen has been followed; i.e. fix leaky seals, seal off unused roadways, install barrier seals and switch to new and better seals. These leaks can be because of a combination of; the way the ventilation is arranged, and the diurnal change in atmospheric pressure. Something can be done about this the ventilation arrangements. A sealed panel, if not pressure balanced, will leak CH_4 out of one side, and leak mine air into the other side. This is most undesirable in three ways;

1) More VAM gas is created than needs to be, causing more fugitive emissions and also potential access issues due to gas in the returns during storms or common diurnal pressure falls.
2) Mine air leaks into sealed areas are to be avoided if possible, due to spontaneous combustion and explosive atmosphere risks.
3) Efforts to prevent the ingress of mine air into the sealed area, and efforts to prevent gas from leaking out of the sealed area cost time and money.

Even so, sealed panels which are not pressure balanced are common in underground coal mines in Australia. In the example here (Figure 5.3) the sealed panels LW8 and LW7B were calculated to have combined due to the strong likelihood of some of the seals between them collapsing during the mining of LW8, in particular 8c/t and 9 c/t, MG8. They can therefore be treated as a single sealed panel for pressure balancing purposes. Given that LW6B was still to be mined, and that it would be undesirable to have the seals in MG6 leaking excessively when put under a potential pressure drop of 412 Pa (as calculated in c above) not only from the point of view of the continuity of production, but from an emissions standpoint, it was decided to induce a negative pressure gradient across from MG6 to MG9.

To enable this, the correct course of action was decided from modelling to put MG9 on full return pressure to pull back the goaf gases in the combined panel away from the MG6 seals as much as possible to prevent CH_4 ingress into the LW6B main-gate. To this end, a ventilation change was made, which removed all regulation in the PG mains returns in A or B hdg and introduced regulation in the form of mine doors in A hdg, MG9 4-5 c/t. Regulation started across the doors at 475 Pa and in succeeding months varied up to 910 Pa as production moved from the ULD to the mining of LW6B in the PG seam; the MG9 seals were basically kept on the existing full return pressure for months before, and throughout the mining of LW6B.

After mining of LW6B commenced, this had the effect of helping to prevent excessive CH_4 movement across from the combined panel into the new LW6B goaf, as it was expected from a geotechnical study that one or two seals in MG6 would probably collapse after the long-wall passed them. The prevention of sudden movements of high-percentage stored CH_4 gas was always a part of the ventilation planning process.

From tube bundle monitoring, the combined panel was known to contain approx. 90% CH_4, therefore it was not possible to increase the CH_4 content in this goaf very much. However, it was possible to do this in other panels, such as the sealed goaf of LW1 in the PG seam; this additional stored CH_4 (by increasing CH_4 concentration in a previously sealed goaf) will be quantified next. However, the initial effect of putting MG9 on full return pressure was to create a pressure balance across the sealed panels and so prevent leakage through seals on all sides of the sealed panel. This reduced the creation of VAM gas. Quantifying this saving in emissions due to the pressure balancing across the sealed panel LW8 and LW7B is described as follows;

Table 5.7 Measurements of CH_4 concentrations in MG6 from a gas survey on 14/11/12

Place measured	CH_4 % general body; 10m out-bye the most in-bye seal noted
MG6 A hdg 3-4 c/t	0.05
MG6 A hdg 4-5 c/t	0.08
MG6 A hdg 5-6 c/t	0.12
MG6 A hdg 6-7 c/t	0.15
MG6 A hdg 7-8 c/t	0.20
MG6 A hdg 8-9 c/t	0.22
MG6 A hdg 9-10 c/t	0.25
MG6 A hdg 10-11 c/t	0.30
Total gas make is:	0.25% of general body flow

As noted earlier, a seal resistance of 1.7 million Ns^2/m^8 needs to be achieved in the seals along MG6 in order to satisfy the strict CH_4 leakage restrictions into MG6. From this position, the resistance of these seals can be calculated prior to the ventilation change to triple the airflow down MG6. This assists with planning the fine detail of the ventilation arrangements for the mining of LW6B.

Measured airflow in MG6, A hdg intake, 4-5 c/t: 28.4 m^3/s
Average make CH_4 28.4 x 0.25% = 71 l/s
Assume all 8 seals involved have the same resistance.
Average seal leakage is approximately; 71/8 = 8.87 l/s

Measured seal pressures during the gas survey are; across 4 c/t seal +200 Pa and across the 10c/t seal +240 Pa therefore MG6 seals are all breathing out (gas survey was deliberately carried out during a diurnal fall in the barometer). The average seal pressure is taken to be +220 Pa.

Find the resistance of the individual seals.

Since; $R = P/Q^2$

$= 220 / 0.00887^2$

$= 2.8 \times 10^6$ Ns^2/m^8

$= 2.8$ million Ns^2/m^8

This gas survey confirms that the seal over-spraying, installation of a second 35 kPa barrier seal and roof and rib spraying has worked and the specified seal target resistance of 1.68×10^6 Ns^2/m^8 was easily achieved.

Average gas make in MG6 before pressure balancing (from ventilation measurements)

= 82.9 l/s

Average gas make in MG6 after pressure balancing (from ventilation measurements)

= 51.1 l/s

Measured mitigation from pressure balancing the sealed panels LW8 and LW7B

= 31.8 l/s

0.641 gm/l x 31.8 = 20.38 gm/s

31,550,000 sec x 20.38 = 643 t/CH_4/yr

643 x 25 GWP = 1.61×10^4 t/CO_2-e/yr

Table 5.8 Balance panels cost calculation

Deputy and ventilation officer's time 50 hours	$5,000
Ventilation change	$2,000
Total	$7,000

5.5.6 Use modelling and pressure to move methane to old goaf voids

As noted above in method 2, a large 20,000 m³ of CH_4 was stored in MG9 and the LW8 back roadway. Another panel where pressure differentials were used to move CH_4 is when the LW101 panel was being mined in the Upper Liddell seam (ULD) which is a lower seam to the PG, being 40 metres lower. In this case, the CH_4 was moved by putting the sealed panel LW1 of the PG seam on full return pressure, through its accessible seals. This amounted to a pressure differential of 250 Pa when compared to the centre of the long-wall of the LW101 panel at start-up and increasing to 515 Pa at the 2/3rd mined stage. Another reason this was done was to prevent CO_2 from coming down onto the long-wall from the old LW1 goaf and causing the statutory CO_2 level of 1.25% in working areas from being exceeded. The CO_2 levels were known to be 9% - 22% in the old LW1 goaf from tube bundle monitoring; the CH_4 levels were also known to be 5% - 10% with negligible levels of O_2. The plan was to keep this overlying goaf inert right through the extraction of the

LW101 panel by causing much of the CH_4 released during the mining to flow upwards using a sufficient pressure differential; the determination of which is not difficult (Loomis). The O_2 was kept low by a strong regimen of surface remediation works, which involved using a dozer over the subsidence-induced surface cracks to rip and then compact the surface wherever cracks were seen.

Excessive O_2 was prevented from flowing upwards from the long-wall by a 'loop' of pressure from the main-gate to the tail-gate; causing the majority of ventilation air to descend down into the tail-gate returns. Other active CH_4 controls were a tight brattice barrier across the main-gate, level with the chocks, a tail-gate brattice barrier and a close back-road bleed to pull CH_4 away from the tail-gate machinery. The mining of LW101 was preceded by extensive modelling, monitoring and calculations to ensure that CH_4 movements were not going to be adverse when the panel was mined. One aim was to ensure that as much CH_4 as possible was left in the combined goafs after LW101 was completed and sealed. This was achieved through buoyancy pressure and differential mine pressure brought about through the ventilation arrangements. CH_4 production from the long-wall which was excessive was drawn off by a surface goaf CH_4 drainage plant, which operated through pre-drilled vertical holes at a spacing of 500m, centred on the panel and ending 17m above the PG seam. The concentration of CH_4 in the LW1 panel was monitored by three pre-existing tube bundle points, and increased from 6% to 30% during the period 20th Sept – 1st Nov 2012. Concentrations of CO_2 and O_2 remained fairly steady. By the completion of the entire LW101 panel, the CH_4 concentration had lifted to 65% in the LW1 PG (the upper seam) goaf. To ascertain the amount of extra CH_4 being stored, the lower LW101 panel goaf needs to be ignored, and count the extra CH_4 stored only in the LW1 PG goaf. The costs involved in this storage were minimal, since the main expense was a limited amount of the ventilation officer's time for ventilation modelling. Surface remediation costs were not included, since they would have happened anyway due to spontaneous combustion and explosive atmosphere concerns.

Volume of LW1 goaf	= ½ volume of removed coal
LW1	= ½ x 1,980 x 2.5 x 210 = 208,162 m^3
Total	= 208,162 m^3

CH_4 increases from an average of 7.5% to an average of 65%.

Pre-existing CH_4 stored	= 7.5% of 208,162
	= 13,530 m^3
New storage amount	= 65% of 208,162 m^3

= 135,305 m^3

Extra amount stored = 135,305 – 13,530

= 121,775 m^3

To this, can be add the 20,000 m^3 which was stored in the unplanned seal-up of MG9 and the LW8 back road;

Total stored = 141,775 m^3

From calculation a, the density of CH_4 under the specified conditions is 0.641 gm/l or 0.641 kg/ m^3

Therefore, the total extra CH_4 stored in these two voids is equal to a CO_2-e of;

141,775 x 0.641 kg = 90.88 t/CH_4

CO_2-e is; 90.88 x 25 = 2.27 x 10^3 t/CO_2-e/yr

Table 5.9 Move methane to old goaf voids cost calculation

Ventilation officer's modelling time 35 hours	$3,500
Ventilation changes	$2,500
Total	$6,000

Table 5.10 Abatements and costs achieved during the trial, using six different measures

Measure 1	8,640	0.48
Measure 2	67,100	1.19
Measure 3	1,000	5.00
Measure 4	316	3.16
Measure 5	16,070	0.43
Measure 6	2,272	2.64
Totals	95,398 t/CO_2-e abated	A$1.08 average cost/t/over the next 12 months

5.5.6.1 Emissions savings made are ongoing – cost per tonne reduces

The average mitigation cost overall as a result of the 12-month trial at the NSW colliery is A$1.08/t/$CO_2$-e over the subsequent 12 months. Stating this latter part is important, because the emissions savings once made, are ongoing. This means that once the mitigation works are done and the works paid for, little or no further investment is required in order to keep the emissions savings going. These are typically measured in litres per second (l/s), and basically keep going as long as the mine lasts. There is some degradation to be expected due to deterioration of seals or other works over time, but these losses are minimal.

What this means is that a more realistic time-frame to measure these mitigation results is a period of 3 years, since mines will on average, keep mining for more than 3 years after any particular moment in time during their mine life. The estimated loss in mitigation over time in terms of litres per second (l/s) is conservatively 10% per year. If measure 2, the seal-up of MG9 is taken as an example, this is what this all means in terms of ongoing costs per tonne and mitigation totals;

Table 5.11 Emissions savings of measure 2, extrapolated over up to five years

Measure 2	Savings t/CO_2-e 1yr	2 yr	**3 yr**	4 yr	5 yr
Savings t	67,100	127,490	**181,840**	230,755	275,000
Cost/t/CO_2-e	A$1.19	A$0.63	**A$0.44**	A$0.35	A$0.29

As can be seen from Table 5.11, both the claimed savings in CO2-e and the cost per tonne in terms of the subsequent year for all measures herein, are both very conservative in that no allowance has been made for the true situation in an operating coal mine, in which emission savings will be ongoing and costs per tonne will then reduce over time.

5.6 Mitigation mechanisms

One might reasonably ask at this point if methane gas is being prevented from entering the mine airstream by whatever means at one point, where does it go? Does it simply enter the mine airstream eventually at some other point? This question gets to the very heart of whether what is claimed here, really occurs; in analysing the results of scientific research, care always has to be taken that mistakes are not made. The final proof is in the measurements presented in Figure 5.2 that says the CH_4 does not re-enter the mine airstream at some other point. So where does the CH_4 go? There are several answers to this question; one answer is explained by Figure 5.1, where the concentration of CH_4 in a sealed panel is measured to increase over time, proving that the total mass of CH_4 being stored in that panel is rising. Another answer is that related to where the CH_4 originates from – i.e. it desorbs from a coal seam. That desorption is pressure-dependent, (Zhao et al., 2012) the CH_4 is adsorbed into the micro-porous matrix of the coal by intra-particle diffusion and it is only when the pressure which keeps the CH_4 in place reduces that it diffuses into the cleats of the coal and may be released. It follows logically then, that *the rate of the release of the CH_4 so adsorbed, is pressure-dependent.* If one takes actions which lower the local pressure, the adsorbed CH_4 will be released at a faster rate; but if one takes actions which raise the local pressure, then the adsorbed CH_4 will release at a slower rate – and some of it may not even release from the coal cleats at all.

A further explanation as to where the mitigated CH_4 might go is that it may be drained from a panel by conventional gas drainage. Most if not all collieries which produce substantial quantities of CH_4 during production have a comprehensive gas drainage system.

This often takes the form of pre-drilled surface to seam gas drainage holes, drilled every 250m or so mid-panel upon which surface gas drainage plants are placed and begin to operate soon after the longwall passes below. After the longwall passes the next gas drainage hole, the surface plant is relocated to it, the old drainage hole is capped, and the process repeats. Basically, after several years of mining, many old mined-out longwall panels remain, each filled with varying percentages of CH_4 gas, and with several capped gas drainage holes in each. For safety and viability reasons, gas drainage work will in any case usually cease when the percentage of CH_4 in the gases being drained from these sealed panels drops below 35%. However, if the percentage and/or quantity of CH_4 gas stored in these panels were to increase substantially due to VAM reduction works such as those detailed here, then it will be possible and viable to re-start gas drainage works from those enriched storage panels.

5.7 The special case of multi-seam long-wall collieries

Fugitive VAM emissions typically comprise 65% of all emissions from a long-wall colliery, and more from a multi-seam colliery (Zhongqing et al., 2010) (Su et al., 2006). Multi-seam longwall mines are becoming more common as mines try to fully work out their lease rather than to seek out a Greenfield site where permits can take many years to acquire, and often involve resistance from anti-coal activism (Morrice & Colagiuri, 2013). A search of “multi-seam long-wall mining in Australia” revealed three results. These mines were found to be in the Hunter Valley at Liddell, Wambo and Ashton. In the case of Liddell and Wambo, the long-walls were mined almost perpendicular to the old long-wall goafs; however, Ashton’s new long-walls were mined parallel (but offset 60m) to the old ones. Papers in relation to these three concentrated mainly on the geotechnical aspects and the associated subsidence issues and very little on the greater VAM emissions associated with multi-seam mining (Miles & Scott, 2014). Other papers that were found on multi-seal long-wall mining in Australia again concentrated on the geotechnical or subsidence aspects of these future mines in the Hunter Valley and in the Bowen Basin. Overall, very little or no research was found on the four identified ventilation issues associated with multi-seam long-wall mining in Australia;

- the additional spontaneous combustion risks specific to multi-seam mining,
- the risk of exceeding statutory gas limits in working areas of the mine,
- the risk of old goaf gases migrating down onto the long-wall and

- the increased risk of developing an explosive atmosphere in both the ‘new’ and the ‘old’ goafs in a multi-seam mine.

Internationally, studies which list any actual experience of multi-seam long-wall mining appear to be limited to China, UK and the USA, again with very limited work in the four identified ventilation issues in a multi-seam long-wall mine. Some work has been done in China on gas flows in multi-seam long-wall mining (Guo, Yuan, Shen, Qu, & Xue, 2012) but little attention was devoted to these four problems. For reasons mentioned elsewhere, multi-seam long-wall mines generally make more VAM gas, and are becoming more common in Australia. However, as the 12-month trial showed in this chapter, this VAM mitigation method works well in this type of colliery. And in the case of Ashton, the long-wall arrangements would be well suited to the implementation of measure six. But whether a single-seam colliery or a multi-seam colliery is under consideration, most emissions are very often in the form of VAM gas, so one question to be asked is; can more be done quickly and cheaply, to reduce these emissions? Chapter six will continue to examine this question, by trying to validate or invalidate the suggestion that the trial results were not unique, and that they can be replicated at other Australian collieries.

6 Chapter 6: The two best mitigation measures are tested

Primary research question;

"Can these specific two mitigation measures be as successful at cutting VAM fugitive emissions at other, typical Australian collieries?"

6.1 Visit to two collieries to collect data for modelling

Background;

- *A 12-month Hunter Valley VAM mitigation trial was conducted using a method which aimed to prevent some CH_4 from entering the mine airstream and becoming VAM in the first place. This was the first known quantified and costed attempt in Australia to reduce fugitive VAM emissions purely for environmental reasons, by using this type of non-gas drainage method. The method involved six measures to reduce emissions by a quantified total of 95,398 t/CO_2-e below that which was projected for the next 12-month period; these emissions savings are on-going.*
- *The two collieries measured and modelled here, have a similar ventilation arrangement, and similar but higher VAM emissions than the NSW colliery in the 12-month study.*
- *Cost of implementation was estimated, and all six measures were found to be very cost-effective.*
- *Safety was also considered, and each measure was individually found to have increased safety at the mine. The most successful two measures in terms of emissions saved, were sealing off an unused roadway and the pressure balancing of a sealed panel. Can these specific two mitigation measures be as successful at cutting VAM fugitive emissions at other, typical Australia collieries?*
- *To ascertain this, these two measures are to be modelled using data from two other Australian collieries (henceforth mine 'A' and mine 'B'). Both measures will be modelled at each colliery, making a total of four modelled scenarios. The results of the modelling will be used to validate or to invalidate the postulate that this method of VAM mitigation, and in particular the two most successful measures used in the 12-month Hunter Valley trial of this method, can work equally well across other Australian long-wall collieries.*
- *From an examination of the mine ventilation plans at mine 'A', and a conversation with the site ventilation officer, the roadway LWC/E take-off road and the sealed panel LWF were identified as the likely targets for the respective modelling simulations.*

- *From an examination of the mine ventilation plans at mine 'B', and a conversation with the site ventilation officer, the LW3-6 chute roads and the sealed panel LW7 were identified as the likely targets for the respective modelling simulations.*

6.2 The data collected and the method of collection - overview

6.2.1 Mine A

2nd August 2016 trip underground;

1. ***Roadway to be modelled – LWC/E take-off road***
2. ***Sealed panel to be modelled – LWF***

- Measured airflows in 6 key locations using an anemometer
- Took 6 gas bag samples from key locations
- Measured pressure across seals in 4 locations
- Put gas bags through the gas chromatograph

3rd August 2016 collecting data from mine records;

- Obtained latest Ventsim file
- Obtained a PDF of the mine
- Obtained historical VAM gas make in relevant returns
- Obtained 30-day tube bundle data from relevant tubes
- Obtained ventilation plan showing airflows and tube monitoring points
- Took monthly ventilation survey files for the last 2 months
- Obtained main fan flows and pressure
- Obtained a 30-day record of the surface air pressure changes

6.2.2 Mine B

4th August 2016 trip underground;

3. ***Roadway to be modelled – LW3-6 chute roads***
4. ***Sealed panel to be modelled – LW7***

- Measured airflows in 6 key locations using an anemometer
- Took 4 gas bag samples from key locations
- Obtained 3-month record of pressure across various seals of LW7
- Put gas bags through the gas chromatograph

5th August 2016 collecting data from mine records;

- Obtained latest Ventsim file
- Obtained a PDF of the mine
- Obtained historical VAM gas make in relevant returns
- Obtained 30-day tube bundle data from relevant tubes
- Obtained ventilation plan showing airflows and tube monitoring points
- Took monthly ventilation survey files for the last 2 months
- Obtained main fan flows and pressure
- Obtained a 30-day record of the surface air pressure changes

6.2.3 How the data will be used

- Data will assist in the modelling of the below four scenarios
- Decide on a display format for the gas, seal pressure, airflow and barometer pressure data
- Decide on what type of Ventsim modelling is best and the display format

6.3 Mine A – Seal-up of a roadway

6.3.1 Modelling the seal-up of LWC/E take-off road

- Model the seal-up of LWC/E take-off road + before and after VAM make
- Graph the expected VAM reductions possible after seal-up
- Calculate projected VAM savings from the seal-up of LWC/E take-off road
- Cost of Works calculation
- Comparison with the 12-month trial results
- Safety Gains Calculations

6.4 Mine A - Pressure balancing of a sealed panel

6.4.1 Modelling the pressure balancing of LWF

- Model the pressure balancing of LWF + before and after VAM make
- Graph the expected VAM reductions possible under different scenarios
- Calculate 12-month VAM savings for the pressure balancing of LWF
- Cost of Works calculation
- Comparison with the 12-month trial results
- Safety Gains Calculation

6.5 Mine B - Seal-up of a roadway

6.5.1 Modelling the seal-up of LW3-6 chute roads

- Model the seal-up of LW3-6 chute roads + before and after VAM make
- Graph the expected VAM reductions possible after seal-up
- Calculate 12-month VAM savings from the seal-up of LW3-6 chute roads
- Cost of Works calculation
- Comparison with the 12-month trial results
- Safety Gains Calculations

6.6 Mine B – Pressure balancing of a sealed panel

6.6.1 Modelling the pressure balancing of LW7

- Model the pressure balancing of LW7 + before and after VAM make
- Graph the expected VAM reductions possible under different scenarios
- Calculate projected 12-month VAM savings for the pressure balancing of LW7
- Cost of Works calculation
- Comparison with the 12-month trial results
- Safety Gains Calculations

6.7 Mine A - Modelling the seal-up of LWC/E take-off road

6.7.1 Take measurements at key locations

This is a high production single-seam longwall mine in the Bowen Basin, has an extractive-fan with a 'U' ventilation arrangement and emits approximately 700,000 t/CO_2-e in VAM emissions annually. These extra VAM mitigation measures detailed here are not normally fully put in place at collieries, once safety and statutory compliance gas levels have been attained. Essentially, residual fugitive emissions are not considered.

Take measurements at key locations of airflows and take a general body gas bag for CH_4 gas concentrations. These were taken at 9:15pm 2nd August, 2016 at MGE A hdg dogleg; 9:30pm 2nd August, 2016 at MGEC hdg dogleg and 9:55pm 2nd August, 2016 at MGC B hdg 1A c/t. (a, b and c respectively on Figure 6.1) The remaining intake roadway; B hdg MGD (point d in Figure 6.1) was not specifically measured, it's relatively low flow is from a ventilation station, (the flow is also confirmed by measurements taken elsewhere) and its CH_4 concentration is taken to be 0.00% CH_4, as is known to be the case from many other measurements taken in the mains intakes at this mine.

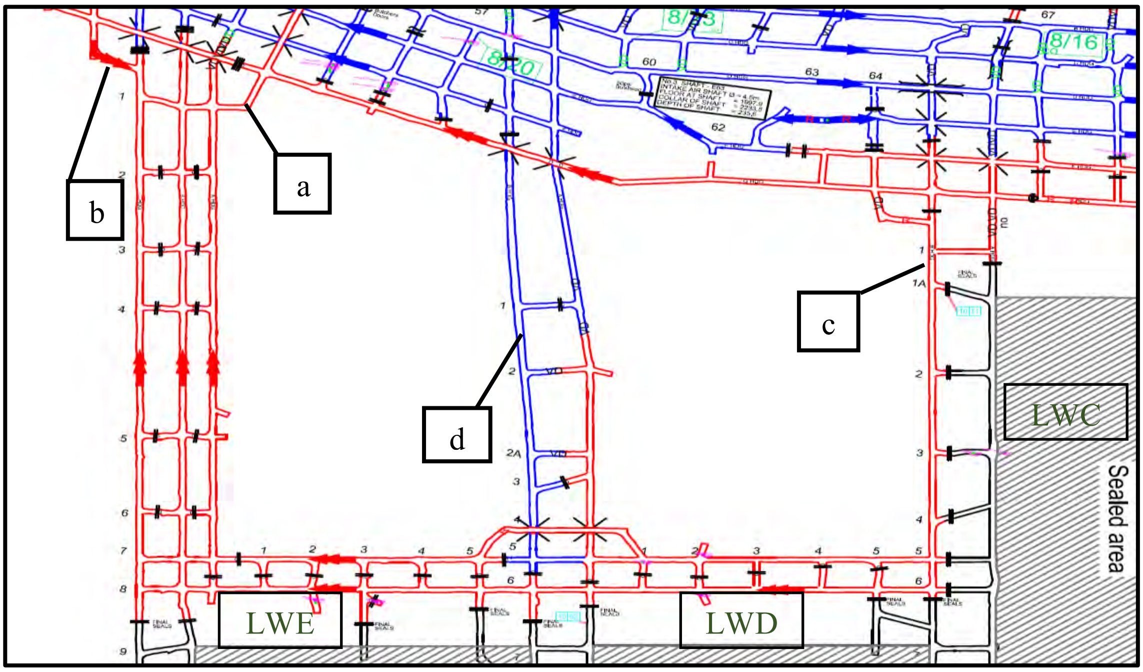


Figure 6.1 The seal-up of LWC/E take-off road

6.7.2 Calculate the actual VAM make from the LWC/E take-off road

Isolating the actual VAM make in the roadway from other CH_4 sources in the mine is simply a matter of measuring the VAM at all the roadway intakes and summing them, then taking this total from the VAM totalled from the return airways. Slight discrepancies in the airflow totals have been used to calculate a maximum and a minimum for VAM in the relevant roadway. CH_4 in each roadway was measured by collecting a general body bag sample, putting it through a gas chromatograph and then normalising the results.

Table 6.1 Measured VAM in roadway intakes

Intakes	Maximum airflow m³/s	Minimum airflow m³/s	CH_4 normalised %	VAM l/s max	VAM l/s min
b	61.2	60.4	0.0097	5.94	5.86
c	35.1	34.7	1.0885	382.06	377.71
d	9.0	8.9	0.0000	0.00	0.00
Totals			VAM intakes;	388.00	383.57

VAM flow in l/s in a roadway is given by the formula; $CH_4\% \times Q \times 10$ (28)

Table 6.2 Measured VAM in roadway returns

Return	Maximum airflow m³/s	Minimum airflow m³/s	CH_4 normalised %	VAM l/s max	VAM l/s min
a	105.3	104.0	0.5001	526.61	520.10
Total			VAM returns;	526.61	520.10

Table 6.3 Measured range of possible VAM make from roadway

Intake VAM max l/s	Intake VAM min l/s	Returns VAM max l/s	Returns VAM min l/s	Make max l/s	Make min l/s
388.00	383.57	526.61	520.10	143.04	132.1

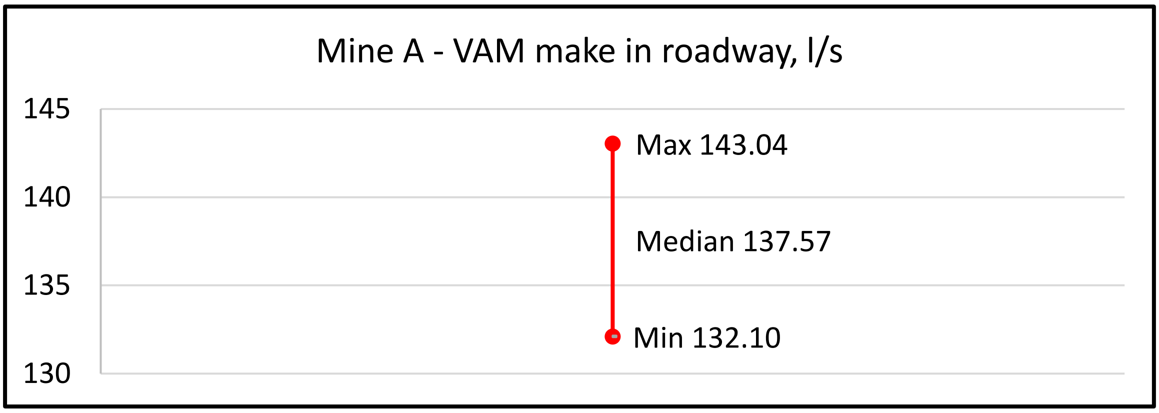


Figure 6.2 The actual median VAM make in the roadway is calculated

6.7.3 Model the measured LWC/E take-off road VAM make

Here Ventsim has been used to show the route that the ~138 l/s of VAM gas which is now known to be the make of this roadway (Figure 6.2), takes through the mine airways. Although the CH_4 leaks into the roadway at many points along it, for simplicity the model shows the total amount injected in full at 2 cut-through, MGC. It then reports to the MGD A hdg dogleg where it comprises 0.14% of the split return air, and finally to surface at No.2 shaft where the concentration drops to 0.03% of the exhaust airflow (Figure 6.3).

The typical Mine A diurnal pressure range is 4hPa (400Pa) and has peaks at around 10pm and 10am and lows at around 4pm and 4am, these figures are taken from the surface mine barometer. Diurnal lows are known to draw more gas out of sealed and unsealed goafs, and so increase general mine VAM gas make; diurnal peaks lower VAM gas make.

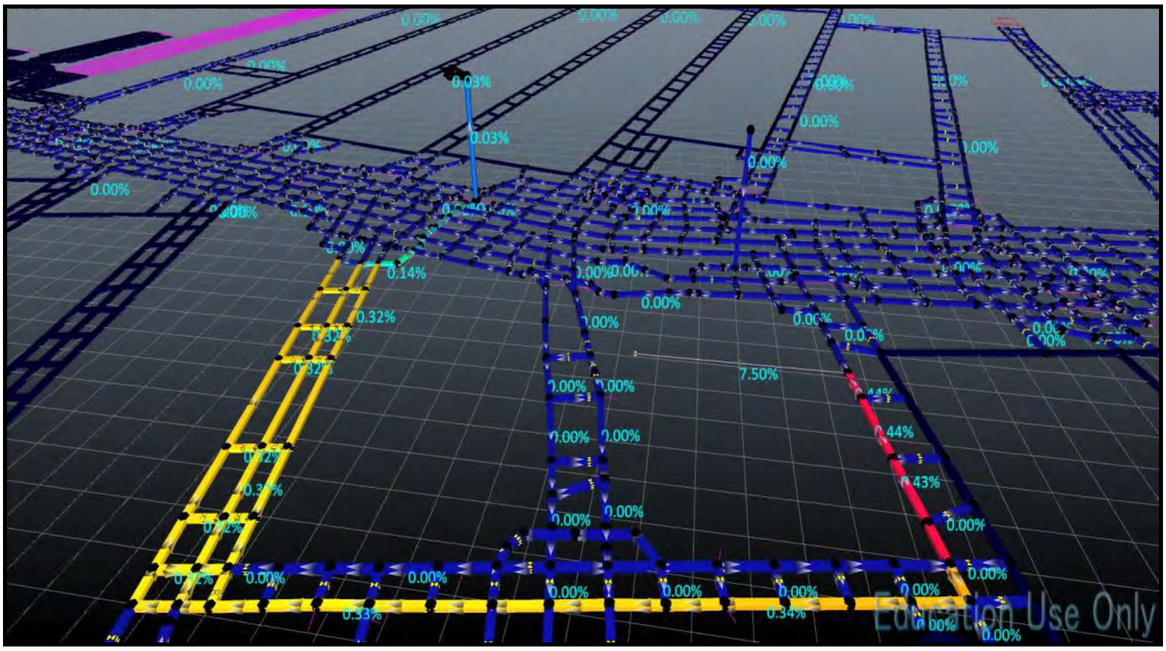


Figure 6.3 The measured roadway VAM make is flow-modelled in Ventsim

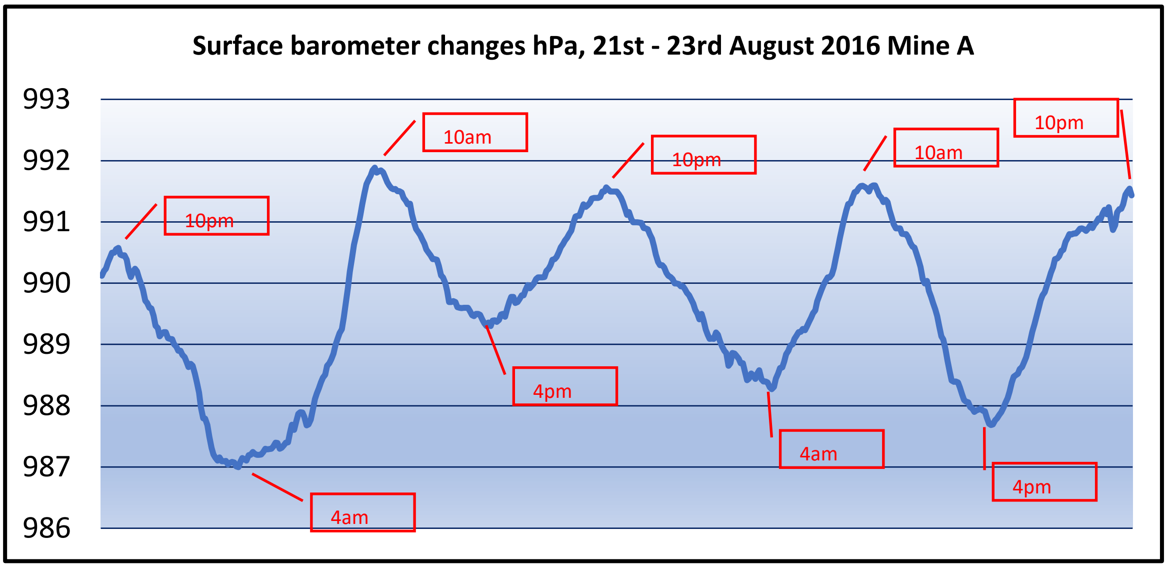


Figure 6.4 Mine A - typical diurnal pressure changes on surface

Note that the gas measurements were done at close to the diurnal peak at around 10pm (Figure 6.4), in this way there will not be an overestimate of the VAM make from the roadway in question, and so consequently overestimate the mitigation being achieved; if anything by taking the measurements at that time it is more likely that an underestimate will occur and so err if anything, on the side of caution.

6.7.4 Theoretically seal-up the roadway by installing 6 x 140 kPa seals

The next step is to model how much VAM gas can be mitigated by sealing-up this roadway. A normal goaf seal in common use in coal mines is rated at 140 kPa, and has a resistance of 15,000 Ns^2/m^8; six of these will be needed to complete the seal-up, and are to be placed in the model at the locations shown.

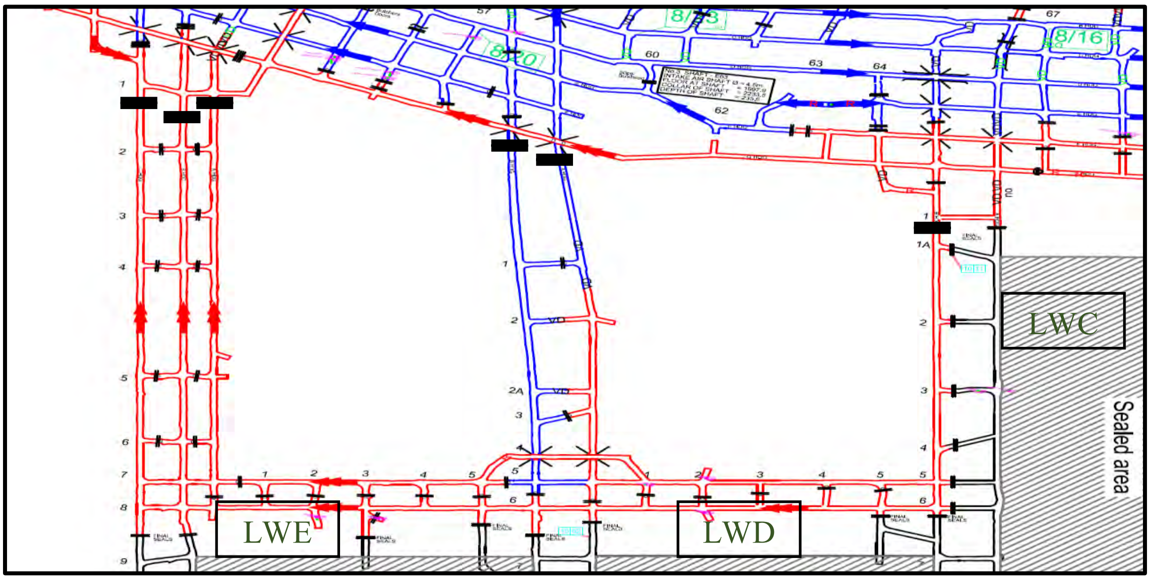


Figure 6.5 The six 140 kPa seals are placed and the roadway is sealed-up

After the roadway is 'sealed-up' in the model (Figure 6.5), an assessment of any continuing CH_4 leakage into the mine airways from the now-sealed roadway is necessary. This leakage will comprise the new VAM make from this part of the mine, and so must be taken off the calculated VAM make from the roadway prior to the seal-up. Essentially, the actual VAM mitigation that can reasonably be claimed from the modelled roadway seal-up will be the difference between the measured VAM make prior to the modelling, and the calculated CH_4 leakage from the sealed-up roadway into the mine.

Table 6.4 Modelled differential pressures across the seven seals

Modelled pressures on the six new seals (and the one original seal) in Pascals						
MGE Chdg	MGE Bhdg	MGE Ahdg	MGD Bhdg	MGD Ahdg	MGC Bhdg	MGC Ahdg
+818	+824	+828	+599	+688	+628	+630

From the positive sign and high numbers, the seals in all seven roadways which formerly served the now-sealed roadway are breathing out strongly, and so must be a source of considerable CH_4 leakage into the mine airflow; which would, if allowed to continue, defeat the purpose of the seal-up. This can be remedied and is to be addressed by performing ventilation changes at each of the three main-gates which were serving the sealed roadway.

6.7.5 Leakage reduction ventilation change – MGE

Both seals breathing out at +818 Pa and +824 Pa respectively, the other seal pressures are also high. Experience informs that this level of pressure across goaf seals leads to too much CH_4 leakage across them. This will defeat the object of reducing the VAM make from this area of the mine; other problems with high seal pressures include an increased risk of spontaneous combustion or the development of explosive atmospheres in the sealed areas. One solution would be to install a second 140 kPa seal in front of those seven which are now sealing the roadway off from working areas of the mine; however, this solution would be expensive and may not prove to be effective.

To remedy this situation easily and cheaply, ventilation changes can be made at each of the places where the newly-sealed roadway meets the mains, to reduce the pressure differential across the seals. Namely, at MGE, MGD and MGC. Figure 6.6 shows the result of a modelled ventilation change at MGE that has been designed to achieve this aim. Measurements need to be taken to ensure that the seals are still generally breathing out after the ventilation change, this is to prevent excessive oxygen ingress into the sealed areas.

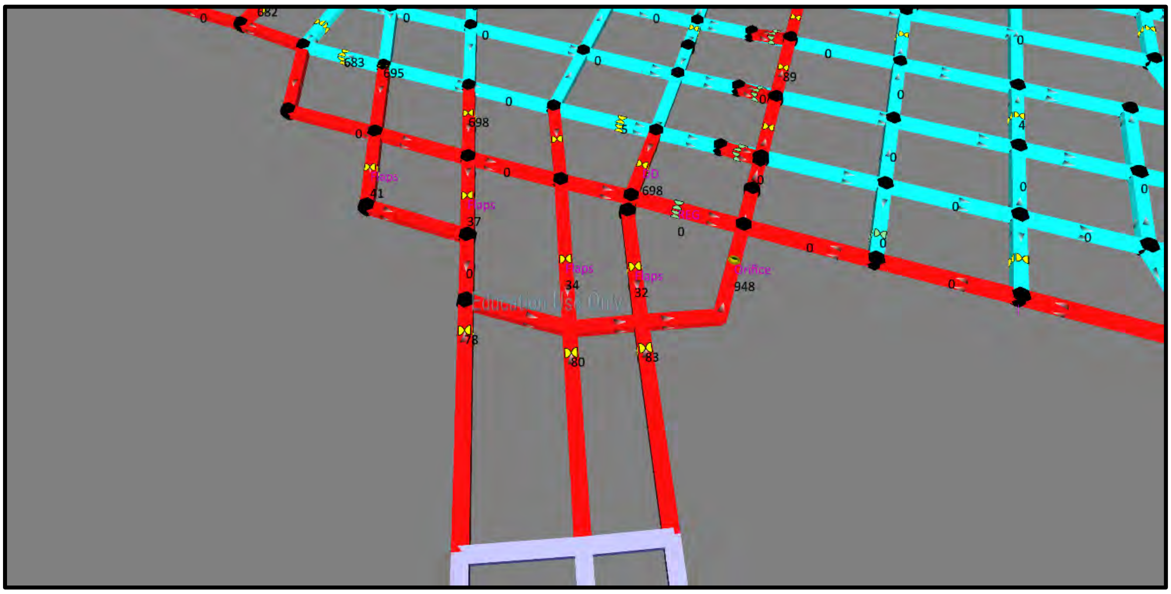


Figure 6.6 Ventilation change at MGE to reduce seal pressures

Works performed during this ventilation change;

- Install butcher's flaps at the four places shown
- Install a 15 kPa stopping with an open man-door (0.7 m^2 orifice)
- Remove the 35 kPa stopping in the mains and replace with a regulator set to a resistance of 0.45 Ns^2/m^8
- The major airflows will remain the same; 64 m^3/s from the out-bye return, 135 m^3/s from the in-bye return and 208 m^3/s flowing to No.2 shaft

6.7.6 Leakage reduction ventilation change – MGD

Figure 6.7 shows the result of a modelled ventilation change at MGD that has been designed to reduce the pressure across those seals.

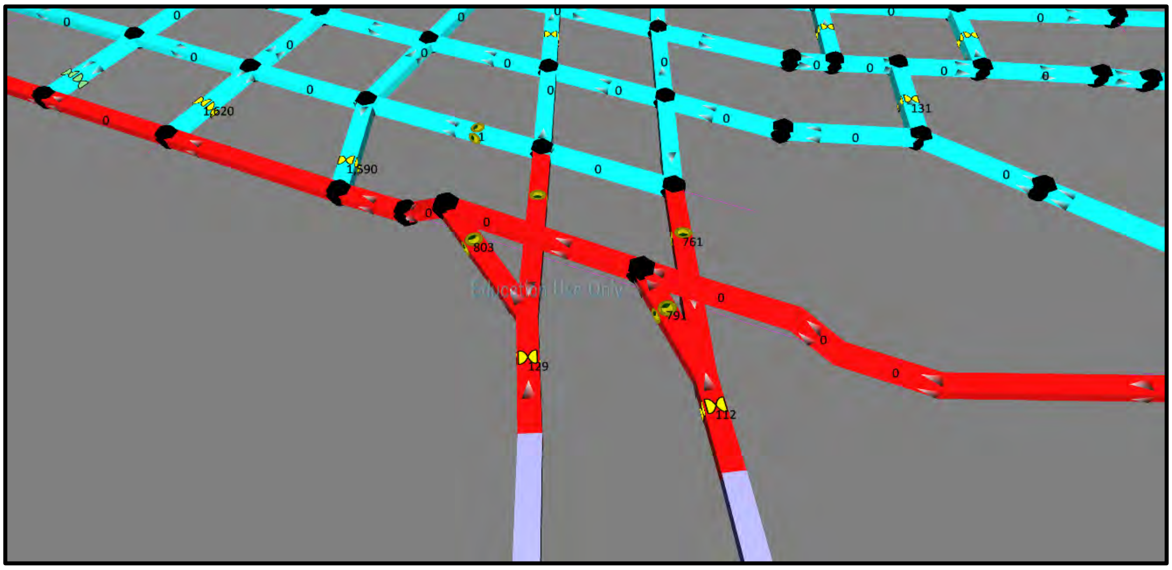


Figure 6.7 Ventilation change at MGD to reduce seal pressures

Works performed during this ventilation change;

- Create leakage at the four places shown; through the overcasts at 0.2 m^2 and through the 35 kPa stoppings in A and B hdg also at 0.2 m^2.
- These orifices create a flow of 4 m^3/s in A hdg and 5 m^3/s in B hdg, which should be sufficient to dilute the reduced seal leakage.
- Major airflows increase very slightly to 139 m^3/s in the out-bye return and to 129 m^3/s in the in-bye return.

6.7.7 Leakage reduction ventilation change – MGC

Because MGC is more remote from the upcast shaft, return pressures are lower, and so it proved to be a little more complicated to lower the seal pressures. It was found to be necessary to put the seals on more of an intake pressure, so the seals were connected to the intake as follows (Figure 6.8);

Works performed during this ventilation change;

- Install a regulator at B hdg dogleg, set to 13 m³/s
- Remove regulator from G mains, out-bye side of MGC
- Install two 15 kPa stoppings in G hdg, mains, one on either side of MGC
- Install flaps A hdg, MGC, between F and G hdg
- Remove regulator from F to G hdg c/t just in-bye A hdg, MGC
- Remove stopping completely from A hdg, MGC in the mains, E to F hdg

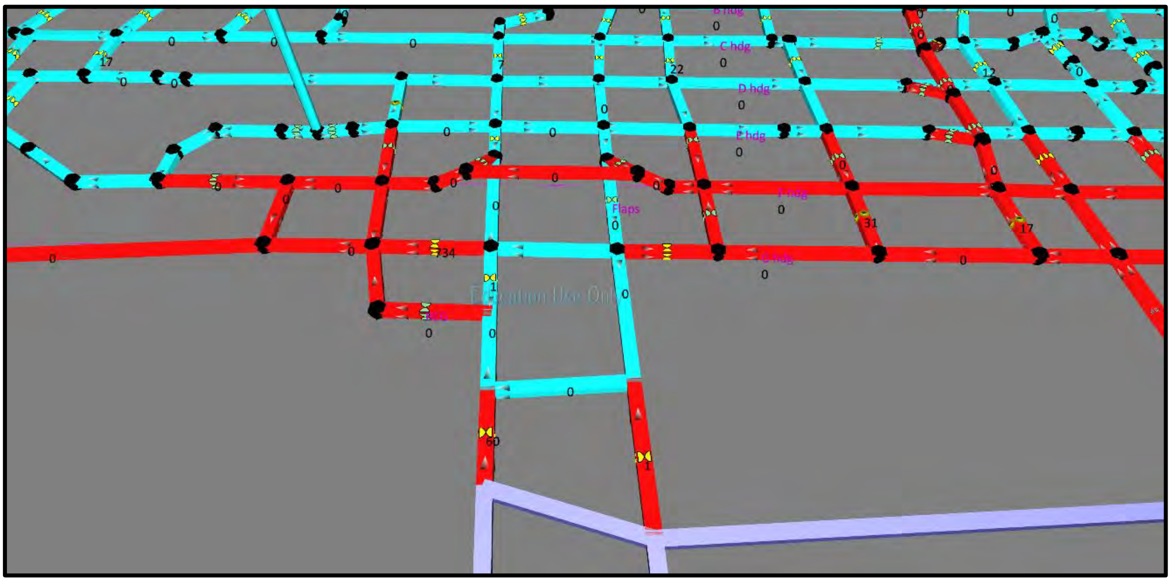


Figure 6.8 Ventilation change at MGC to reduce seal pressures

As this final ventilation change was done, the seal pressures in MGD and MGE changed slightly, but all were still breathing out. The final seal pressures are as follows;

Table 6.5 Differential pressures across the seven seals after the ventilation changes

Modelled pressures on the seven new seals in Pascals after all ventilation changes						
MGE C hdg	MGE B hdg	MGE A hdg	MGD B hdg	MGD A hdg	MGC B hdg	MGC A hdg
+78	+80	+83	+129	+112	+60	+1

6.7.8 Calculation of the leakage from the LWC/E take-off road

The median leakage into the roadway (simply, the VAM make from the roadway) is 137.57 l/s. In terms of mitigation, this represents the maximum possible VAM savings which could be achieved by sealing up this roadway. However, in practice, there will be some leakage from the sealed goafs LWC, LWD and LWE across the seven seals and into the mine airways. This needs to be kept to a minimum, because it directly reduces the final VAM mitigation quantity. There will generally be positive pressure on these seals (i.e. they are breathing out) because of their direct connection to the return airways directly after the roadway seal-up. Given this, there are two ways to keep the leakage to a minimum;

- Build excellent seals – (or two of them in series at each point), and / or
- Lower the differential pressure across the seals if it is too high

Given that a second 140 kPa seal is to be constructed in front of existing goaf seals, the situation here is similar to that existing in MG6 of the original mitigation trial in NSW. And there, leakage measurements showed that each set of seals reached a resistance of 3.5 x 10^6 Ns^2/m^8. To reach this rating, the 140 kPa seals were sprayed over again, and up to 4m of rib and roof was also sprayed to a depth of 50mm. Then a second rated barrier stopping was installed in front of that seal, and again, the roof and ribs were sprayed out to 4m and to a 50mm depth. Given that in this case, these methods are to be followed, and even enhanced by the use of a 140 kPa seal instead of a 35 kPa stopping, it is reasonable to use this resistance for the seal pairs. Calculating the leakage is done by looking at the seals in all seven access roadways in the model, and assessing;

- Whether the seal is breathing in or out and if breathing out;
- Calculating the leakage from the seal (Q) by knowing the pressure on the seal (P) and the resistance of the seal (R)
- Assumes a turbulent flow of gas in the leakage

The formulae which applies is; $Q = \sqrt{P/R}$ (29)

Where;

Q is the gas leakage in m^3/s.
P is the modelled median differential pressure across the seal.
R is the seal resistance in Ns^2/m^8

A figure of 3.5 x 10^6 Ns^2/m^8 is used for the seal resistance across the two 140 kPa seals, because this was the measured resistance achieved across a well-constructed 140 kPa seal and a 35 kPa stopping pair, built during the NSW mitigation trial, while trying to reach a 1.68 x 10^6 Ns^2/m^8 goal for leakage prevention.

Table 6.6 Calculated leakage in l/s through the seven seals

Modelled pressures on the seven seals in Pascals after all ventilation changes						
MGE C hdg	MGE B hdg	MGE A hdg	MGD B hdg	MGD A hdg	MGC B hdg	MGC A hdg
$=\sqrt{\left(\frac{78}{3500000}\right)}$	$=\sqrt{\left(\frac{80}{3500000}\right)}$	$=\sqrt{\left(\frac{83}{3500000}\right)}$	$=\sqrt{\left(\frac{129}{3500000}\right)}$	$=\sqrt{\left(\frac{112}{3500000}\right)}$	$=\sqrt{\left(\frac{60}{3500000}\right)}$	$=\sqrt{\left(\frac{1}{3500000}\right)}$
4.7	4.8	4.9	6.0	5.7	4.1	0.5

Total predicted leakage from the seven seals is therefore 30.7 l/s. Note that this is not VAM leakage, but is total gas leakage, some of which is CH_4 which will become VAM.

To assess how much of this gas leakage will contribute to VAM leakage across the seals, the percentage of CH_4 in each panel at the out-bye end will need to be looked at.

Table 6.7 Measured CH_4 concentration in the out-bye end of each sealed panel

LWC	90%
LWD	80%
LWE	60%

The gas leakage across the three seals is thus;

Table 6.8 Total of VAM leakage across seals

Panel	Gas leakage l/s	Percentage CH_4	VAM leakage l/s
LWC	4.6	90%	4.1
LWD	11.7	80%	9.4
LWE	14.4	60%	8.6
		Total VAM leakage;	22.0 l/s

6.7.9 Mitigation available by sealing the LWC/E take-off roadways

The total expected residual VAM leakage is therefore 22.0 l/s, which gives a net VAM saving due to the roadway seal-up of; 137.57 – 22.0 = 115.57 l/s.

Using calculation 'a' for the CH_4 density);

0.641 gm/l x 115.47 = 74.0 gm/s

31,550,000sec x 74.0 = 2,335 t/CH_4/yr

2,335 x 25 GWP = 5.838×10^4 t/CO_2-e/yr saved

6.7.10 Cost of works calculation for roadway seal-up

Table 6.9 Costs compared; trial roadway seal-up and Mine A roadway seal-up costs

Cost item	Trial roadway seal-up cost A$	Mine A seal-up of roadway LWC/E cost A$
Deputy and VO's time	10,000	15,000
Risk assessment	12,000	12,000
Seal-up doors x 2	11,000	nil
Pipework/clearing roadway	20,000	10,000
Ventilation change & seal-up	9,000	24,000
Monitoring costs	2,000	2,000
Seal costs	16,000	96,000
Totals	80,000	159,000

The cost of works comparison is as expected, with the Mine A roadway seal-up works projected to cost almost twice as much as the works for this same measure during the 12-month trial. The reason for the projected higher cost is the extra seals required and the extra ventilation works (Table 6.9).

6.7.11 Comparison with the 12-month trial seal-up results

Table 6.10 VAM abatement; comparison between the trial seal-up and Mine A seal-up

	VAM abated in l/s	VAM in gm/s	Tonnes CH_4/yr	10^4 tonnes CO_2-e/yr
Trial seal-up	132.75	85.1	2,684	6.710
Mine A LWC/E seal-up	115.47	74.0	2,335	5.838

The final VAM abatement comparison from this measure is surprisingly similar, given that these are completely different mines, even located in different states. It is an encouraging result however, because it lends credence to the overall concept that this mitigation methodology can and will work satisfactorily in disparate places and coal seams.

6.7.12 A comparison of the mitigation costs

Table 6.11 Mitigation costs in A$ per t/CO_2-e over the next year and the next three years

	Cost per t/CO_2-e over next 1 yr A$	Cost per t/CO_2-e over next 3 yr A$
NSW Trial seal-up	1.19	0.40
Mine A LWC/E seal-up	2.72	0.91

Finally, a comparison of the mitigation costs of the roadway seal-up for each mine (Table 6.11). Since the costs associated with the seal-up of the LWC/E take-off roadway are projected to be approximately twice those of sealing-up MG9 in the Hunter Valley trial was, the mitigation costs are also doubled. However, they are still far below other mitigation costs in other areas of the economy, such as for solar and wind (Wharburton et al., 2014), afforestation projects (Van Kooten, Shaikh, & Suchánek, 2002), or direct-action auction costs (Clean Energy Regulator, 2016), as detailed in Table 6.12.

Table 6.12 Comparing costs; this mitigation method vs other industries

Mitigation method	**Approximate cost per t/CO_2-e abated in A$**
Small-scale solar photo-voltaic mitigation	~200
Large-scale wind farm mitigation	~80 to ~120
Afforestation projects	~25
Direct-action auction cost (2016)	~10
Non-gas drainage method modelling / Mine A	0.38 to 2.72

6.7.13 Safety gains from sealing the LWC/E take-off road

Sealing the roadway brings with it several possible safety gains, including;

- Better machinery access to the returns during diurnal lows
- Reduced need for seal inspections, due to there being 7 seals instead of 15
- Reduced roadwork maintenance
- Less likelihood of a seal collapse due to there being less seals

- Less roadway inspections needed
- Lower need for service supply and maintenance
- Lower monitoring requirement
- More barriers separating the working areas from any possible fire, explosion or spontaneous combustion incidents in the LWD, LW107 and LWE goafs
- Less fugitive GHG emissions in the form of VAM

6.8 Mine A - Modelling the pressure balancing of LWF

6.8.1 Take measurements at key locations

The VAM make of the sealed panel LWF was measured in the following way. Airflow measurements, seal pressures, general body temperatures and gas bags were taken for CH_4 concentrations at key locations. These were measured and taken around the sealed panel LWF at 11am 2nd August 2016 on the back road; 12 noon to 1pm 2nd August 2016 along MGF at 14 c/t, 3-5 c/t and 1-2 c/t; and 1pm 2nd August 2016 on the panel take-off road at the return end. The intake air on the back road comes from a nearby downcast shaft, and is known to be fresh air. However, for the sake of completeness this was still confirmed by taking a general body gas bag and putting it through the mine gas chromatograph.

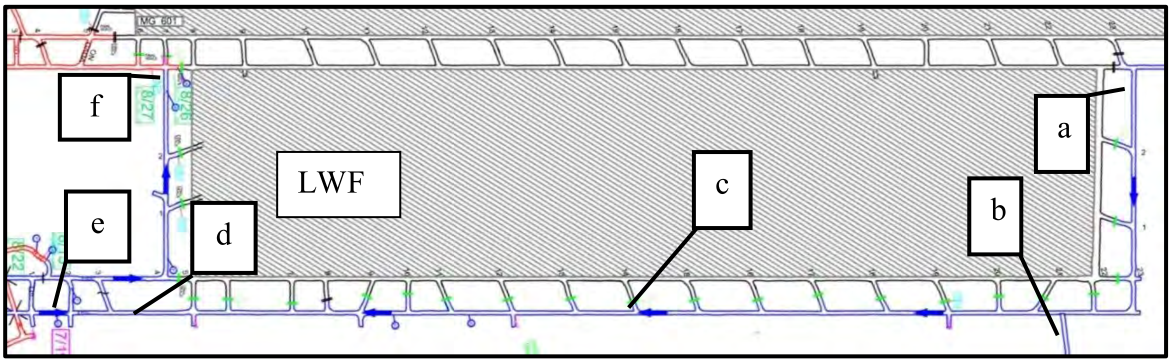


Figure 6.9 Sealed panel to be pressure balanced is LWF

6.8.2 Calculate the actual VAM make from LWF

To measure the VAM make from the sealed panel LWF, it is only necessary to know the VAM content at the return end (Figure 6.9) of the take-off road (f) and at (b); this is because both intakes (a and e) when measured on the day, showed no measurable CH_4 content. Diurnal pressure at Mine A (surface) is known to peak at 10am and has a low at around 4pm (Figure 6.4). The gas bags and airflow measurements were taken between 11am and 1pm, therefore would be representative of an average VAM make for the sealed panel LWF (Figure 6.10).

Table 6.13 Measured VAM in roadway intakes

Intakes	Maximum airflow m^3/s	Minimum airflow m^3/s	CH_4 normalised %	VAM l/s maximum	VAM l/s minimum
a	28.6	28.6	0.0000	0.0	0.0
e	53.4	53.4	0.0000	0.0	0.0
Total			VAM intakes	0.0	0.0

Table 6.14 Measured and calculated VAM in roadway returns

Returns	Maximum airflow m^3/s	Minimum airflow m^3/s	CH_4 normalised %	VAM l/s maximum	VAM l/s minimum
b	8.8	8.8	0.03 (estimate)	2.64	2.64
dogleg	10.0	10.0	Calculated VAM	3.29	3.29
f	73.2	62.4	0.2110	154.45	131.66
Total			VAM returns	160.38	137.59

Table 6.15 Measured range of possible VAM make from roadway

Intake VAM maximum l/s	Intake VAM minimum l/s	VAM make maximum l/s	VAM make median l/s	VAM make minimum l/s
0.00	0.00	160.38	148.98	137.59

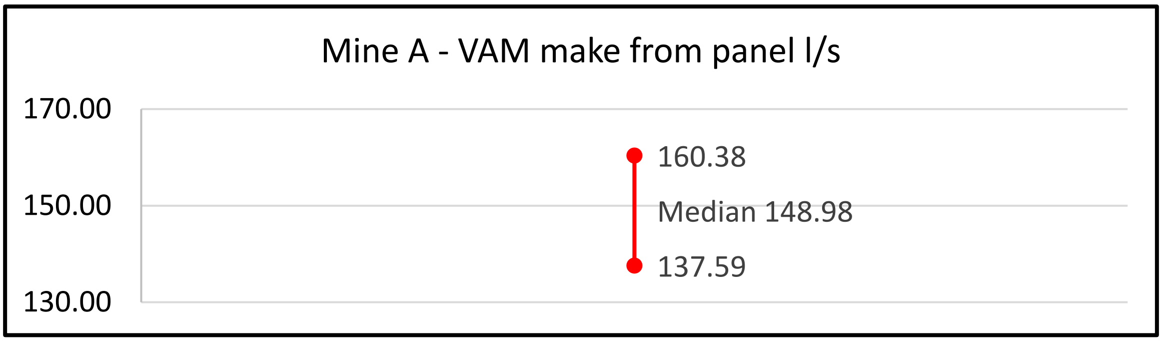


Figure 6.10 The measured median VAM make from the sealed panel LWF

Because a gas bag sample was taken from MGF 3-5 c/t, the overall make of the sealed panel can be confirmed by calculating the VAM make from MGF separately;

Table 6.16 VAM make from MGF

3-5 c/t	Maximum airflow m^3/s	Minimum airflow m^3/s	CH_4 normalised %	VAM make l/s maximum
d	19.8	19.8	0.1207	23.89

It can be seen from this that the clear majority of the leakage from the panel is directly into LWF take-off road. This knowledge will be invaluable in assisting the decision making when it comes to exactly how to balance this panel for the greatest mitigation effect.

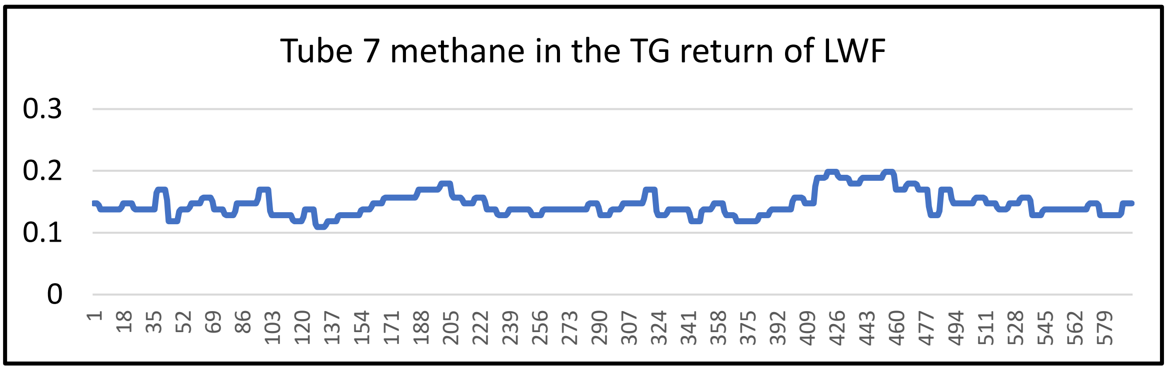


Figure 6.11 Tube 7 CH_4 from LWF return in TG

For comparison with the general body bag sample taken from LWF return, 600 consecutive measurements from tube 7 have been graphed (Figure 6.11), which is also in the LWF return. These cover the period 21st June 2016 to the 24th June 2016; surface pressure effects can be clearly seen. This samples the mine air directly every six minutes, (with a delay of 40 minutes) through an infra-red detector on the surface. Sampling often, and directly from the mine air, tube bundle systems are very useful for trends and for safely sampling for the development of explosive atmospheres. Nevertheless, they are known to be less accurate at measuring very low values of any gas, including CH_4, than gas chromatographs, this is why the general body gas bag samples are preferred and have been used in calculations.

6.8.3 Model the initial measured panel VAM make on Ventsim

Here Ventsim has been used to show the route that the ~149 l/s of VAM gas which is now known to be the make of this sealed panel takes through the mine airways.

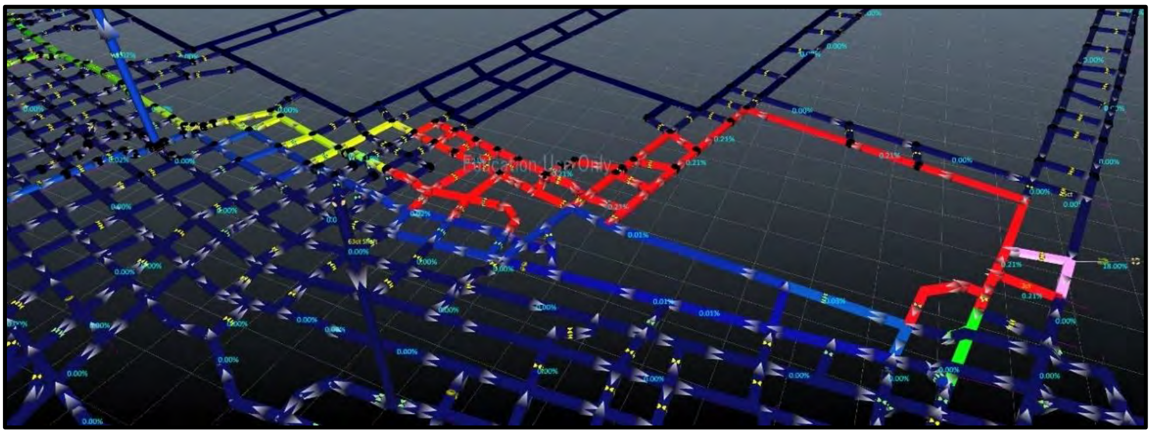


Figure 6.12 Route taken by the VAM gas make from sealed panel LWF

Although the CH_4 leaks into the roadway at many points along it, for simplicity the model shows the total amount injected in full at 3 cut-through, MGF. The small amount of VAM (2.64 l/s) which traverses the cross-cut at point b will be ignored in the balancing simulations, since close to this amount will probably continue after the balancing of the panel anyway. The bulk of the VAM make from the sealed panel reports to the returns in TGF. A small amount of the VAM from MGF reports to the MGF dogleg return;

Airflow at MGF dogleg;	10 m^3/s
Airflow on LWF take-off roadway;	62.4 m^3/s
Amount of VAM make from MGF;	23.89 l/s
Proportion of VAM make reporting to MGF dogleg;	10/72.4 = 13.8%
VAM reporting to MGF dogleg;	23.89 x 0.138
	= 3.29 l/s

This amount is added to the VAM make at point b and point f to arrive at the total panel VAM make. The panel VAM make is highest at 0.21% in LWF take-off road, then remains over 0.2% (in red) until it gets diluted in the MG 600 returns to 0.15% (yellow) then splits to take three circuitous routes to exit shaft No.2 at 0.02% and exit shaft No.1 at 0.04% (Figure 6.12).

6.8.4 Theoretically pressure balance LWF panel in the following way;

The panel is basically on intake pressure at the in-bye end, because the bleeder road is fed unregulated from a nearby downcast-shaft. To pressure balance LWF, the panel will be isolated from the return pressures at the out-by end with a regulator (R3) placed in TGF dogleg, the effect of this will be to reduce the pressure differential down the length of the panel. The ventilation change consists of the works detailed in Figure 6.13 and are as follows; Remove the stopping in TGF 4 c/t, remove the regulation (R1) in the mains return, adjust the regulator in the MGF dogleg (R2) and the insert butcher's flaps in MGF, 1-2 c/t. The aim of the change is to isolate the out-bye end of LWF from the return pressure and to reduce the airflow across the take-off roadway from 62 m^3/s to 28 m^3/s.

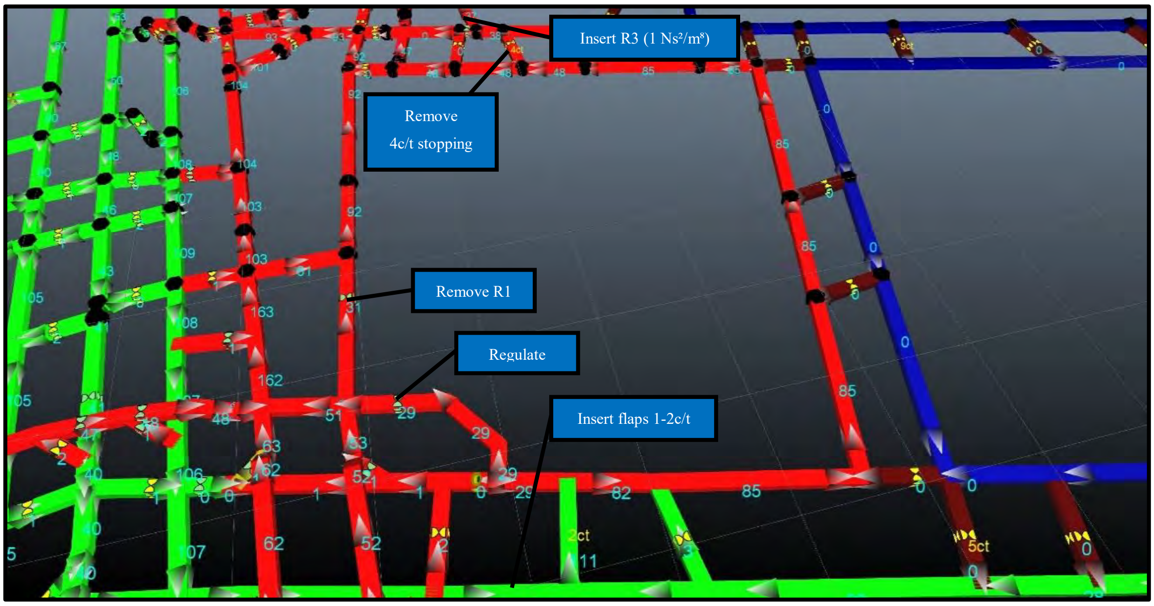


Figure 6.13 LWF take-off road and mains area ventilation works

6.8.5 The effect of the ventilation change on seal pressures and gas leakage

The model indicates that the pressure across the take-off roadway seals will be reduced to the following average ranges; in MGF generally 8-17Pa; in the LWF take-off roadway 30-33Pa. CH_4 gas levels in LWF are measured by the tube bundle system to be 29% in-bye and 65% out-bye. To calculate residual gas leakage across the seals, the formulae to be used is;

$$Q = \sqrt{P}/R$$

Because the residual pressure across all the MGF seals is so low and similar, one representative seal will be used to represent all its 21 seals, and then extrapolated across them. And similarly, because the residual pressure across those seals in LWF take-off roadway are so low and similar, again, one representative seal will be extrapolated across those 4 seals. The figure of 3.5×10^6 Ns^2/m^8 is used for seal resistance.

Table 6.17 Calculated gas leakage in l/s through two representative seals

Modelled pressures on the two seals in Pascals after the Ventilation change	
LWF T/off roadway seal	MGF typical seal
$Q = \sqrt{\left(\frac{32}{3500000}\right)}$	$Q = \sqrt{\left(\frac{12}{3500000}\right)}$
Leakage = 3.0 l/s	Leakage = 1.8 l/s

Gas leakage LWF T/off roadway = 4 x 3.0 = 12.0 l/s

Gas leakage MGF roadway = 21 x 1.8 = 37.8 l/s

Total predicted gas leakage from the seven seals is therefore 49.8 l/s. To assess how much gas leakage will contribute to VAM leakage across the seals, the percentage of CH_4 content in the panel along the main-gate and at the out-bye end is needed.

Table 6.18 Measured CH_4 concentration in the sealed panel

Average behind MGF and bleeder road seals	29%
Average behind LWF T/off seals	65%

The estimated VAM gas leakage across all LWF seals is thus;

Table 6.19 Total of VAM leakage across all LWF seals

Roadway	Gas leakage in l/s	% CH_4	VAM leakage in l/s
T/off Road	12.0	65%	7.8
MGF + bleeder	37.8	29%	10.9
		Total VAM leakage;	18.7 l/s

The total expected residual VAM leakage is 18.7 l/s, which gives a net VAM saving due to the panel seal-up of; 149.0 – 18.7 = 130.3 l/s

6.8.6 Mitigation available by balancing panel LWF

Average VAM gas make LWF before pressure balancing = 149.0 l/s
Average VAM gas make LWF after pressure balancing = 18.7 l/s
Expected VAM mitigation from pressure balancing LWF = 130.3 l/s

This mitigation quantity, when projected over a subsequent 12-month period has a CO_2 -e equivalent of;

0.641 gm/litre x 130.3 = 83.52 gm/s
31,550,000sec x 83.52 = 2,635 t/CH_4/yr
2,635 x 25 GWP = 6.587 x 10^4 t/CO_2-e / year

6.8.7 Cost of works calculation for panel pressure balancing

Table 6.20 Costs compared; trial pressure balancing and Mine A balancing LWF

Cost item	Trial balancing cost A$	Mine A balancing LWF A$
Deputy and VO's time	5,000	5,000
Risk assessment	-	5,000
Move regulator R1 to R3	-	5,000
Pipework / clearing roadway	-	5,000
Ventilation change	2,000	2,000
Adjust regulator R2	-	-
Flaps to TGF 1-2 c/t	-	3,000
Totals	7,000	25,000

The cost of works comparison is as expected, with the Mine A pressure balancing of LWF to cost more than the works for this same measure during the 12-month trial. The reason for the projected higher cost is the extra works required for the ventilation change, and the risk assessment costs (Table 6.20).

6.8.8 Comparison with the 12-month trial results

Table 6.21 VAM comparison between the trial pressure balancing and LWF balancing

	VAM abated in l/s	VAM in gm/s	T/ CH_4/yr	10^4 t/ CO_2-e/yr
Trial balancing	31.8	20.38	643	1.61
Mine A LWF	130.3	83.52	2,635	6.59

The final VAM abatement comparison shows that far more abatement is possible from LWF. The costs to balance the panel were much higher due to the extra works, which needed the input of several mineworkers for several shifts. Nevertheless, the mitigation costs were still very low.

6.8.9 Overview of the safety gains by pressure balancing LWF

Pressure balancing LWF brings with it several possible safety gains, including;

- A lower risk of a spontaneous combustion event in the panel
- A lower risk of developing a large volume of explosive gases
- Better machinery access to the returns during diurnal lows
- Less likelihood of a seal collapse due to there being less pressure on the seals
- Lower monitoring requirement due to the greater likelihood of an inert atmosphere
- Less fugitive GHG emissions in the form of VAM

6.9 Mine B - Modelling the seal-up of LW3-6 chute roads

6.9.1 Take measurements at key locations

This is a large single-seam longwall mine in the Bowen Basin, has an extractive-fan with a ‘U’ ventilation arrangement and emits approximately 600,000 t/CO_2-e in VAM emissions annually. These extra VAM mitigation measures detailed here are not normally fully put in place at collieries, once safety and statutory compliance gas levels have been attained. Essentially, residual fugitive emissions are not considered.

At Mine B, there was not an obvious candidate roadway to seal-up, as there often is in in a colliery of this age, as there was in the Hunter Valley trial mine, and as there was in Mine A. Thus, the chute roads which run along the sealed panels LW3, 4, 5, and 6 were selected for the modelled seal-up; this would not normally be done for ventilation resistance reasons, but is done here for modelling VAM savings. First take a general body gas bag for CH_4 gas concentrations at a key location, this was LW4 chute road on the return side; sample was taken at 2:30pm on the 9th August 2016. The four intake roadways are to have their airflows and VAM flows measured. Additionally, there is a small amount of leakage into the chute roads, which has been estimated for flow and VAM content (Figure 6.14).

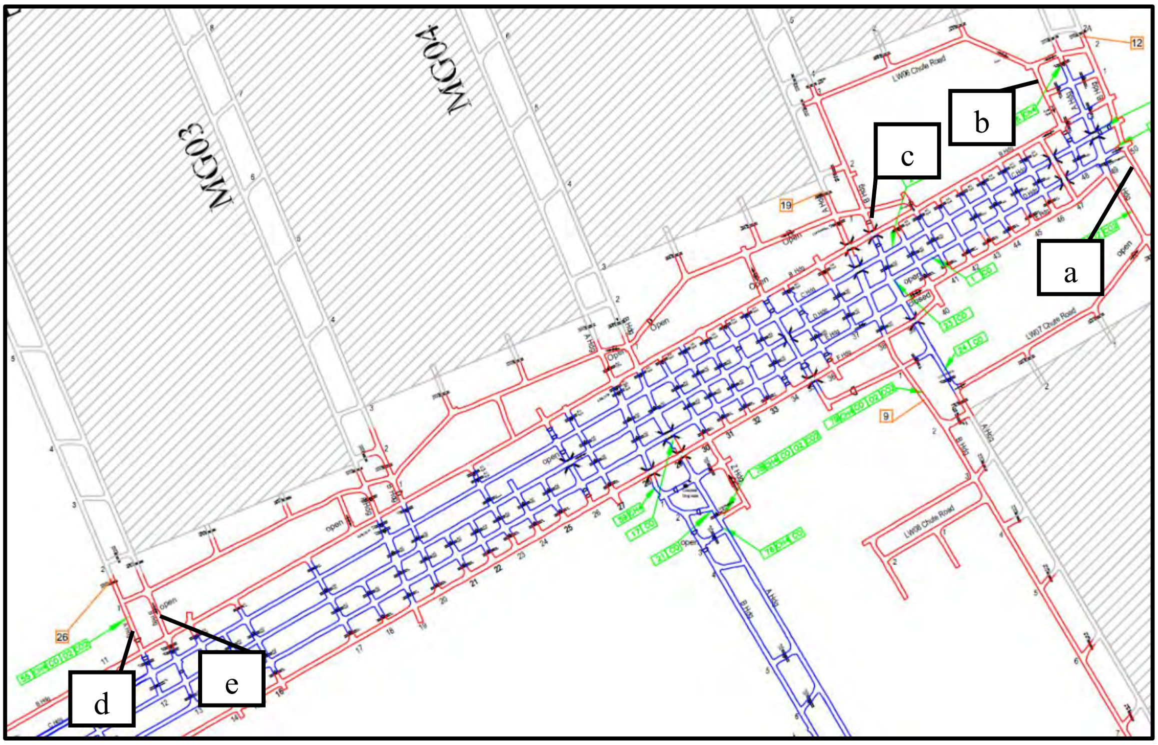


Figure 6.14 Measuring the VAM make from the LW 3-6 chute roads

The CH_4 concentration of the two intake roadways is taken to be 0.00% as is known to be the case from many previous measurements taken in the mains intakes at this mine.

6.9.2 Calculate the actual VAM make from the LW3-6 chute roads

Isolating the actual VAM make in the roadway from other CH_4 sources in the mine is simply a matter of measuring the VAM at all the roadway intakes and summing them, then taking this total from the VAM totalled from the return airways. Slight discrepancies in the airflow totals have been used to calculate a maximum and a minimum for VAM in the relevant roadway. CH_4 in each roadway was measured by either averaging the last several hundred readings from the relevant tube or real-time detector, or collecting a general body bag sample, and putting it through a gas chromatograph and then normalising the results (Figures 6.15 and 6.16) (Tables 6.22 6.23 and 6.24).

Roadway air flows were either taken from ventilation stations, monthly ventilation reports, or measured at the time of the mine visit. Very little leakage occurs from B hdg, mains across the stoppings to the chute roads because both roadways are at a similar gauge pressure. The CH_4 concentration in the sealed goafs behind the chute roads is high ~68% and all seals breathe out into the chute roads.

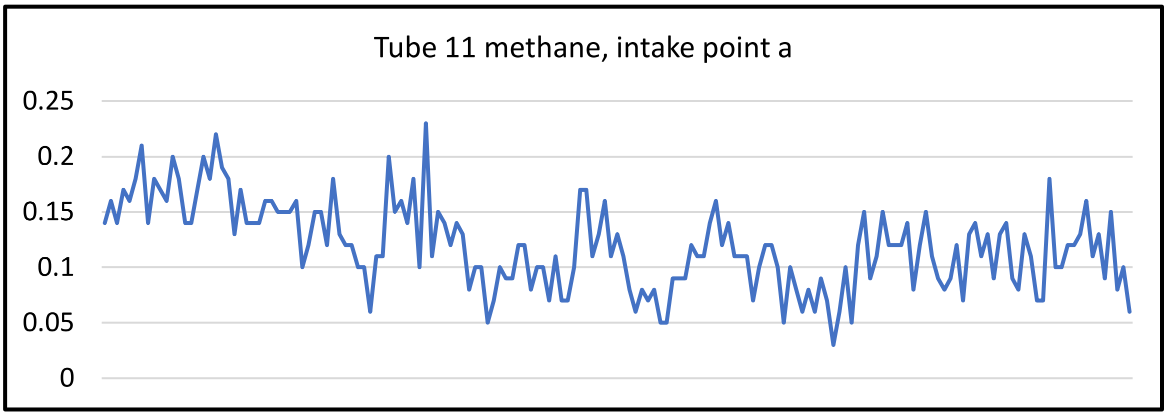


Figure 6.15 Tube 11 CH_4 trend of 120 samples, (intakes point a)

Table 6.22 Measured VAM in roadway intakes

Intakes	Max air m³/s	Min air m³/s	CH_4 averaged %	VAM l/s max	VAM l/s min
a	46.0	44.0	0.11	50.6	48.4
b	35.0	34.5	0.0000	0.00	0.00
c	8.5	8.0	0.0000	0.00	0.00
Total			VAM intakes	50.6	48.4

VAM flow in l/s in a roadway is given by the formulae; $CH_4\% \times Q \times 10$ (30)

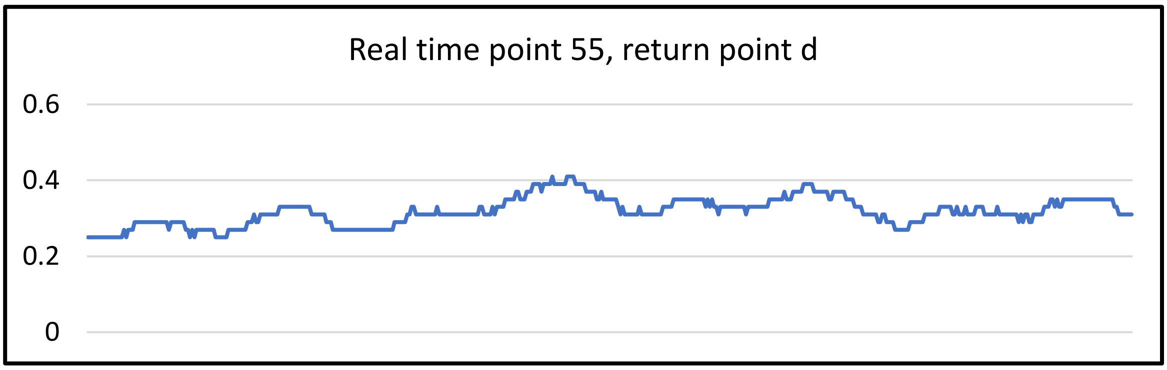


Figure 6.16 Real time point 55 CH_4 trend of 430 samples, (returns point d)

Table 6.23 Measured VAM in roadway returns

Return	Maximum airflow m³/s	Minimum airflow m³/s	CH_4 averaged %	VAM l/s maximum	VAM l/s minimum
d	69.0	67.0	0.32	220.8	214.4
e	22.0	21.0	0,32	70.4	67.2
Total			VAM returns	291.2	281.6

CH_4 levels were not measured in the return airway at point e. They are taken to be identical to the levels at point d, given that these points are from basically the same airstream, which has been split.

Table 6.24 Measured range of possible VAM make from roadway

Intake VAM maximum	Intake VAM minimum	Returns VAM maximum	Returns VAM minimum	Make VAM maximum	Make VAM minimum
50.6 l/s	48.4 l/s	291.2 l/s	281.6 l/s	242.8 l/s	231.0 l/s

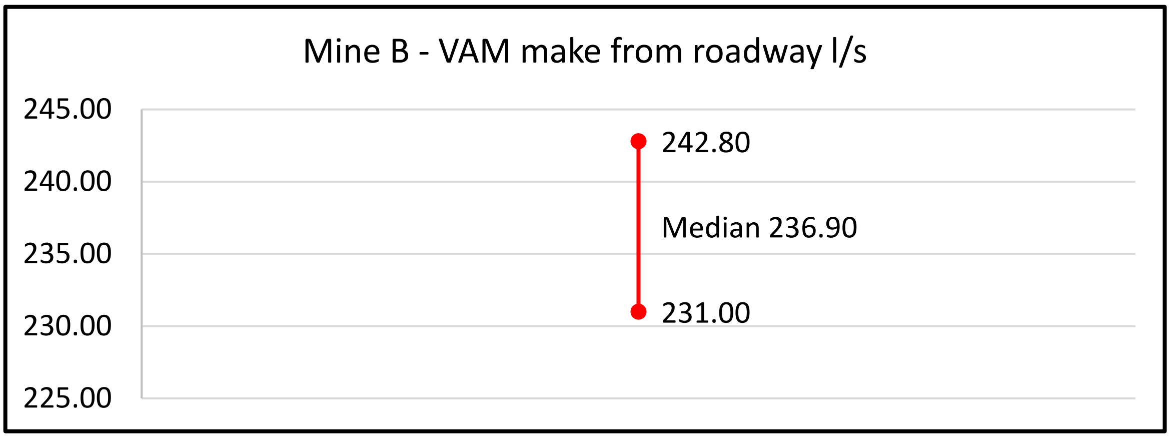


Figure 6.17 Range of VAM make from the LW3-6 chute roads

6.9.3 Model the measured LW3-6 chute roads VAM make on Ventsim

Here Ventsim has been used to show the route that the ~236.9 l/s of VAM gas which is now known to be the make of this roadway (Figure 6.17), takes through the mine airways. Although the CH_4 leaks into the roadway at many points along it, for simplicity the model shows the total amount injected in full at 50 cut-through, MG6. After exiting the chute roads at 0.32%, it then reports to B hdg, mains, where it comprises 0.17% of the split return air, and along the returns to surface at No.1 shaft where the concentration drops to 0.08% of the exhaust mine airflow (Figure 6.18).

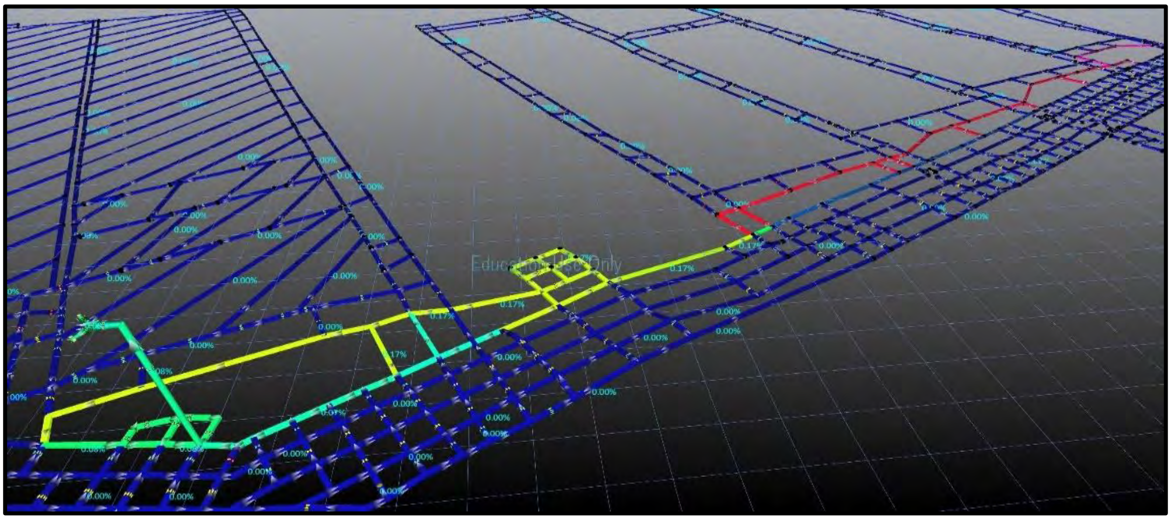


Figure 6.18 The measured roadway VAM; route is flow-modelled in Ventsim

It will be noted that the LW3-6 chute roads form a twin return pathway with the B hdg, mains. These two returns are separated by simple unrated ventilation stoppings with man-doors, and some single machine doorways for machinery access. There is almost no differential pressure across these stoppings, and hence, almost no leakage. The leakage has been considered, and is represented in Figure 6.19.

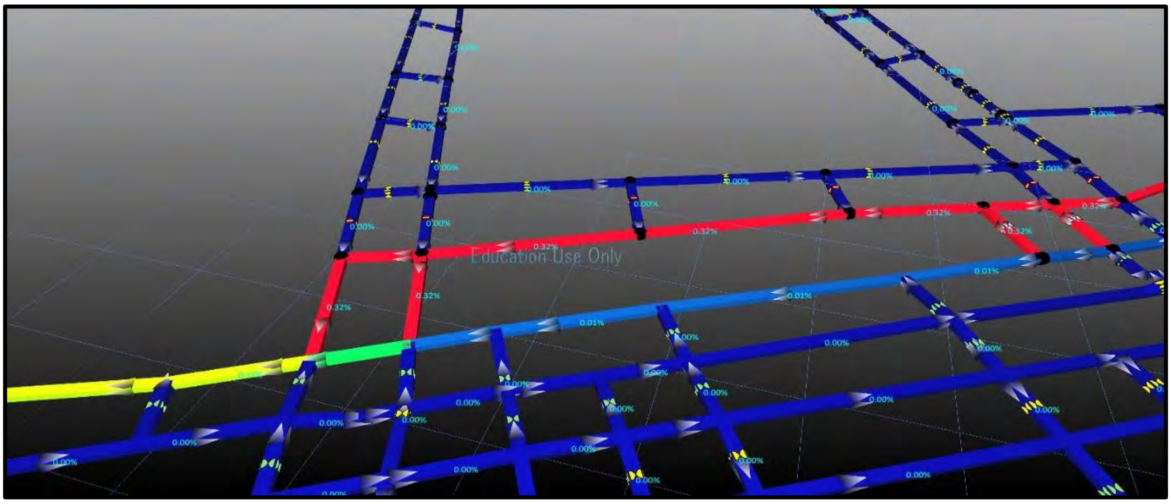


Figure 6.19 VAM leakage across to ‘B’ hdg, mains

The leakage is modelled at 0.1% VAM going into the B hdg, mains roadway airflow, which is 83 m³/s this is equivalent to 1/32 of the VAM, or 7 l/s. The likelihood is that a similar leakage goes across the other way to the chute roads, and so this leakage is ignored. Note that the actual gas measurements from the tube and the real-time detectors cross several diurnal peaks and lows, and so are representative of the actual average VAM make from these chute roadways.

6.9.4 Seal-up the LW3-6 chute roads by shotcreting all stoppings

The next step is to model how much VAM gas can be mitigated by sealing-up this roadway. A normal goaf seal in common use at this mine is rated at 140 kPa and has a resistance of 15,000 Ns^2/m^8; four of these will be needed, and eleven mine plaster over-sprays of existing stoppings to 140 kPa, to complete the seal-up. They are to be placed at the locations shown in Figure 6.20. The seal design to be used is detailed in Figure 6.21, which is the high strength water resistant mine plaster type. This seal is a new design, and although rated at 140 kPa is only 20cm thick and is quick and easy to install; and it can be erected by spraying over old stoppings. According to the model, the seal-up will reduce return airflow out-bye of the works, from 179 m³/s to 141 m³/s, which is acceptable; the cause of this is the increased resistance of the returns, because of going to a single heading.

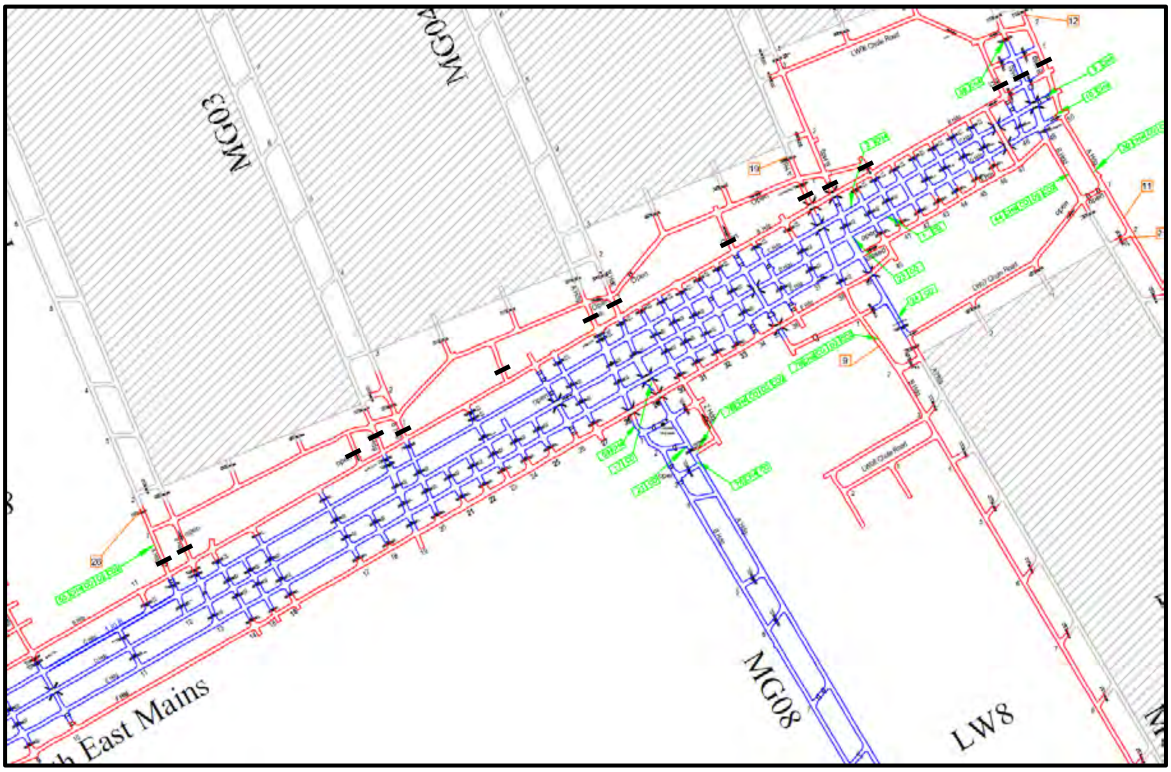


Figure 6.20 Four 140 kPa seals and twelve 140 kPa mine plaster over-sprays are needed

An assessment of any continuing CH_4 leakage into the mine airways from the now-sealed roadway is necessary. This leakage will comprise the new VAM make from this part of the mine, and so must be taken off the measured VAM make from the roadway prior to the seal-up.

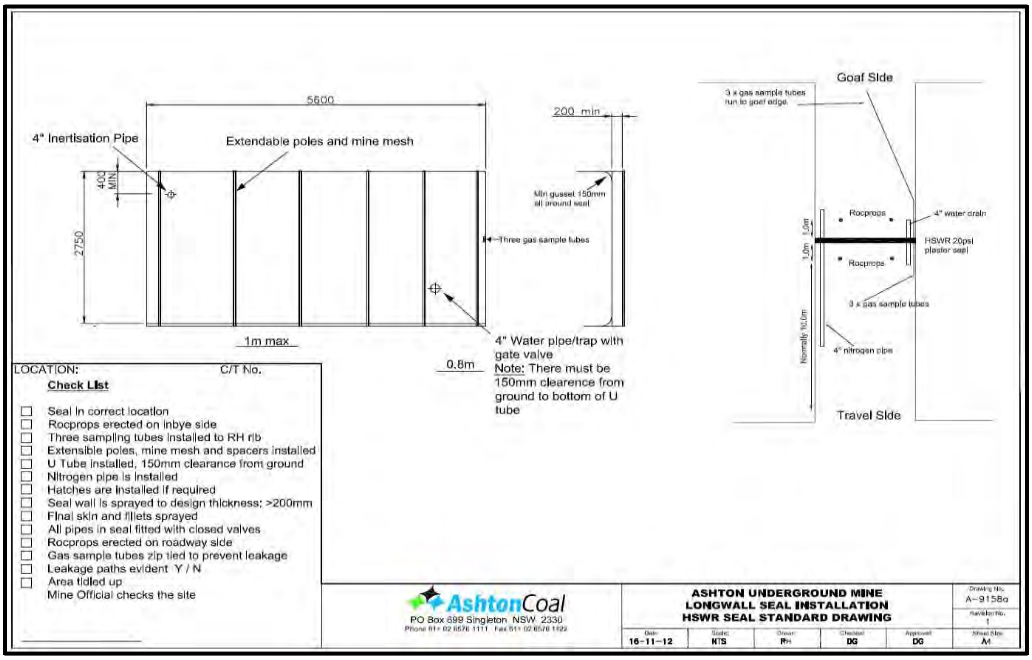


Figure 6.21 High strength water resistant mine plaster 140 kPa seal (Ashton Coal, 2012)

Essentially, the actual VAM mitigation that can reasonably be claimed from the modelled roadway seal-up will be the difference between the measured VAM make prior to the modelling, and the calculated CH_4 leakage from the newly sealed-up chute roadways into the mine returns. Assessing the leakage is done by looking at the seals in all fifteen access roadways in the model and;

- Whether the seal is breathing in or out and if breathing out;
- Calculating the leakage from the seal (Q) by knowing the average pressure on the seal (P) and the resistance of the seal (R) according to; $Q = \sqrt{P/R}$

Table 6.25 Modelled differential pressures of the fifteen seals in Pa

Seal 1	Seal 2	Seal 3	Seal 4	Seal 5	Seal 6	Seal 7	Seal 8	Seal 9	Seal 10	Seal 11	Seal 12	Seal 13	Seal 14	Seal 15
-76	-75	-68	-25	0	+148	+165	+208	+232	+278	+342	+358	+374	+488	+503

The seals are numbered from in-bye to out-bye. The gradual increase in differentials is partly due to the lowering gauge pressure along B hdg, mains, and partly due to some restrictions in the overcasts in MG5. It was determined to clear some of the restrictions in the overcasts by clean-up works at those locations. The result was an increase in airflow out-bye of the seal-up works to 150 m³/s, which is satisfactory, and a lowering of seal pressures as follows;

Table 6.26 Seal differential pressures in Pa after the overcast works

Seal 1	Seal 2	Seal 3	Seal 4	Seal 5	Seal 6	Seal 7	Seal 8	Seal 9	Seal 10	Seal 11	Seal 12	Seal 13	Seal 14	Seal 15
-48	-42	+2	+17	+31	+39	+69	+119	+142	+199	+262	+290	+308	+438	+455

The gauge pressure behind all the seals was found to be almost the same; and the methane concentration was also similar and averaged 68%. The overcast works were deemed to be worthwhile, since they reduced gas leakage into the returns.

6.9.5 Calculation of the residual leakage from the LW3-6 chute roads

The median leakage into the roadway (simply, the VAM make from the chute roads) is 236.9 l/s. This is the maximum possible VAM saving which could be achieved by sealing up this roadway. To calculate the actual VAM mitigation of the seal-up, the leakage across those fifteen seals into B hdg, mains needs to be worked out. The pressures across the seals have been reduced somewhat due to the overcast works, and another factor is that the gas has to cross two 140 kPa seals to enter the mine returns; assuming the chute roads were sealed by nitrogen injection, then this represents a further barrier (although a temporary one) to the entry of methane from sealed areas into the workings. Roadway size at Mine B is 5.9 m wide and 3.6 m high giving a perimeter of 19 m and an area of 21.2 m².

Residual gas leakage across the seals, the formulae is;

$$Q = \sqrt{P}/R$$

Where;

Q is the gas leakage in m^3/s.
P is the modelled median differential pressure across the seal.
R is the 'double' seal resistance, as defined previously to be 3.5m Ns^2/m^8.

Table 6.27 Calculated gas leakage in l/s through the first seven seals

Calculated gas leakage from the first seven seals, after overcast works						
Seal 1	Seal 2	Seal 3	Seal 4	Seal 5	Seal 6	Seal 7
Seal breathing in	Seal breathing in	$\sqrt{\left(\frac{2}{3500000}\right)}$	$\sqrt{\left(\frac{17}{3500000}\right)}$	$\sqrt{\left(\frac{31}{3500000}\right)}$	$\sqrt{\left(\frac{39}{3500000}\right)}$	$\sqrt{\left(\frac{69}{3500000}\right)}$
nil	nil	0.75	2.20	2.97	3.33	4.44

Table 6.28 Calculated gas leakage in l/s through the last eight seals

Seal 8	Seal 9	Seal 10	Seal 11	Seal 12	Seal 13	Seal 14	Seal 15
$\sqrt{\left(\frac{119}{3500000}\right)}$	$\sqrt{\left(\frac{142}{3500000}\right)}$	$\sqrt{\left(\frac{199}{3500000}\right)}$	$\sqrt{\left(\frac{262}{3500000}\right)}$	$\sqrt{\left(\frac{290}{3500000}\right)}$	$\sqrt{\left(\frac{308}{3500000}\right)}$	$\sqrt{\left(\frac{438}{3500000}\right)}$	$\sqrt{\left(\frac{455}{3500000}\right)}$
5.83	6.37	7.54	8.65	9.10	9.38	11.10	11.40

Total predicted leakage from the fifteen seals is therefore 83.06 l/s. Note that this is not CH_4 leakage, but is total gas leakage, some of which is CH_4. The only goaf CH_4 concentration measure available is from LW3, this was 68% and so this is the figure which will be used here. The leakage across the seals is 83.06 l/s, which is deemed to be 68% CH_4. VAM make from seal leakage to the return is; 83.06 x 0.68 = 56.48 l/s.

6.9.6 Mitigation available by sealing the LW3-6 chute roads

The total expected residual VAM leakage is therefore 56.48 l/s, which gives a net VAM saving due to the chute roads seal-up of;

137.57 – 56.48 = 81.09 l/s.

This percentage of mitigation represented here is not ideal, but it is true that the before figure is a conservative number, taken on a barometric high; and it is also true that more could be done to reduce leakage into B hdg, mains from these seals, for example by reducing the pressure across them further.

Using the prior calculation for the CH_4 density;

0.641 gm/litre x 81.09	= 51.9 gm/s
31,550,000sec x 51.9	= 1,637 $t/CH_4/yr$
1,637 x 25 GWP	= 4.09 x 10^4 t/CO_2-e/yr saved

6.9.7 Nitrogen sealing of the roadway

The seal-up is to be done using nitrogen, using the on-site floxal plant. It would be cheaper to open the seals to the four goafs and use the methane for this, but two problems are associated with this method; the concentration of the methane may be too low, and it is desirable for leakage minimisation to keep the original seals intact. The volume of the roadway to be sealed is 39,750 m^3 and the flow rate of the nitrogen plant is 0.6 m^3/s. The aim is to reduce the O_2 level in the roadway to below 12% and keep it there through monitoring and further injection when required, which will prevent any explosive atmosphere from forming. The time taken to reduce the roadway atmosphere to this safe level is;

6.9.7.1 Calculated time to inertise the 1,875m roadway;

Volume of roadway; 1,875m x 21.2 m^2 = 39,750 m^3
N_2 needed in roadway to displace oxygen = 39,750 ÷ 2.35 = ~17,000
N_2 required to inertise roadway; 17,000 m^3
Estimated time to reach >12% O_2 is 17,000/0.6 = 28,300 sec = ~8 hours

All the middle seals are completed first, then the start and end seals are built with a man-door in each. Then the injection of N_2 can start. The floxal plant will need to be run for ~8 hours; when the gases exiting the man-door in the last seal are <12% O_2, the seal-up can take place.

6.9.8 Cost of works calculation for LW 3-6 chute roadway seal-up

Table 6.29 Costs compared; trial seal-up of MG9 vs the seal-up of LW3-6 chute roads

Cost item	Trial seal-up A$	Mine B seal-up A$
Deputy and VO's time	10,000	5,000
Risk assessment	12,000	10,000
Seal-up doors x 2	11,000	11,000
Pipework & clearing roadway	20,000	-
11 seal oversprays to 140 kPa	-	44,000
4 new 140 kPa HSWR seals	-	32,000
Ventilation changes & seal-up	25,000	8,000
Nitrogen seal-up costs	-	8,000
Monitoring costs	2,000	5,000
Totals	80,000	123,000

The cost of works comparison shows that the seal-up costs are significantly higher than the seal-p of MG9 during the trial in NSW. A large part of this is the many extra seals required, and the floxal plant running costs.

6.9.9 Comparison with the 12-month trial results

Table 6.30 VAM comparison; trial seal-up of MG9 vs the seal-up of LW3-6 chute roads

	VAM abated l/s	VAM abated gm/s	Tonnes CH_4/yr	10^4 tonnes CO_2-e/yr
NSW trial seal-up	132.75	85.1	2,684	6.71
Mine B seal-up	81.09	51.9	1,637	4.09

The final VAM abatement comparison shows that less abatement is possible from these chute roads than from the seal-up of MG9 in the trial. The costs to achieve this smaller emissions cut was 50% higher. The result is a mitigation cost of over A$3/t CO_2-e, which although high in the context of other costs with this method, are still far below even the already comparatively low average of direct-action auction prices.

6.9.10 Overview of the safety gains by sealing the LW3-6 chute roads

- Better machinery access to the returns during diurnal lows
- Reduced roadway maintenance
- Less roadway inspections needed
- Lower need for services supply and maintenance
- More barriers separating the working areas from any possible fire, explosion or spontaneous combustion incidents in the LW3, LW4, LW5 and LW6 goafs
- Less fugitive GHG emissions in the form of VAM

6.10 Mine B - Modelling the pressure balancing of LW7

6.10.1 Take measurements at key locations

At Mine B, there was only one candidate panel for pressure balancing; LW7. The VAM make of the sealed panel LW7 was measured in the following way. Airflow measurements, seal pressures, general body temperatures, tube bundle and real time data and gas bags were taken for CH_4 concentrations at key locations (Figure 6.22). The intake air is supplied from the out-bye end of MG07, which amounts to 33 m^3/s (a), and is fed directly from the mains, which at this mine is known to be fresh air. The rest of the intake air, which totals 114 m^3/s (b), and is supplied to the back road, comes directly from the mains and around an un-mined panel, and is known to be very close to fresh air.

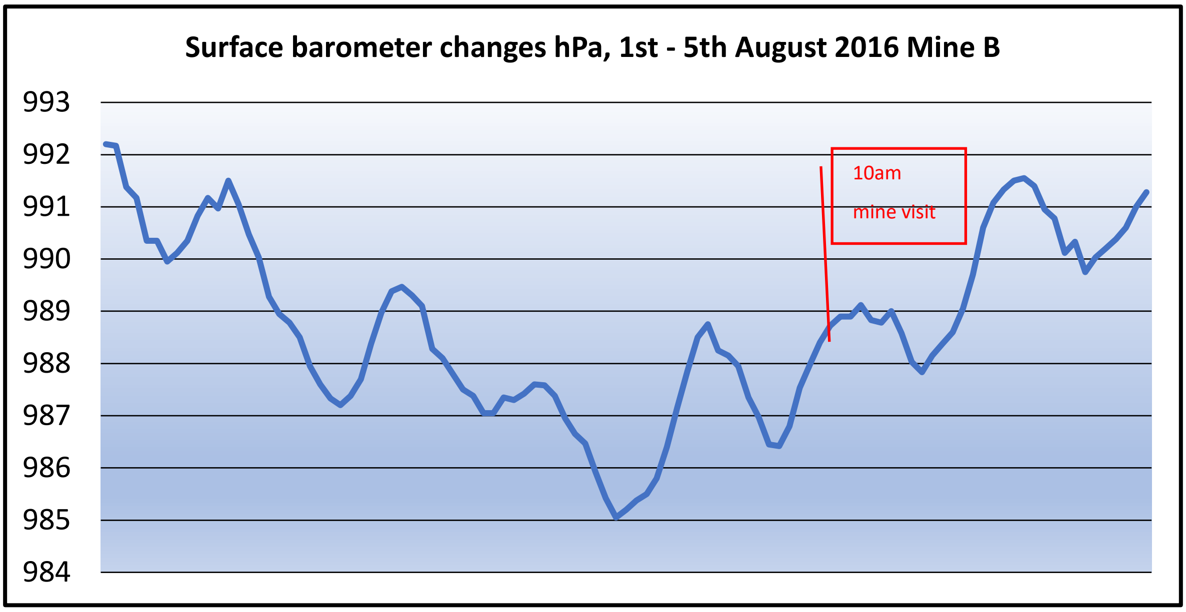


Figure 6.22 Sealed panel LW7 is to be pressure balanced

Some of the return air reports to the out-bye end of the main-gate and is 61 m³/s (c). The balance of the return air travels equally along the tail-gate roadways, totals 86 m³/s (d).

6.10.2 Calculate the actual VAM make from LW7

To ascertain the VAM make from the sealed panel LW7, it is only necessary to know the VAM content at the twin tail-gate return roadways (d) and the main-gate return roadway (c); this is because all intakes (a and b) when measured on the day, showed very little CH_4 content. These intakes are supplied almost directly from the mains, which are known at this mine to have no significant CH^4 content, due to the flanking returns in the mains. Diurnal pressure at Mine B (on surface) is known to peak at 10am and has a low at around 4pm.

Figure 6.23 The surface barometer changes as recorded during the Mine B visit

It will be noted that there was a strongly rising barometer overall during the Mine B visit on the 4th August (Figure 6.23). Although the timing during the day of the visit underground was made to avoid measuring the excessive gas makes apparent during a rapidly falling barometer, the actual day itself could not be changed. These circumstances mean that the gas readings taken underground may not be representative of the average, and so will not be used; historical gas tube bundle data that covers several diurnal cycles will be used instead. However, the roadway airflow readings were unaffected and are used.

Table 6.31 Measured VAM in LW7 panel intakes

Intakes	Maximum airflow m^3/s	Minimum airflow m^3/s	CH_4 normalised %	VAM l/s maximum	VAM l/s minimum
a	33.5	32.5	0.0000	0.0	0.0
b	115.0	113.0	0.0010	1.2	1.1
Total			intakes	1.2	1.1

Table 6.32 Measured and calculated VAM in LW7 panel returns

Return	Maximum airflow m^3/s	Minimum airflow m^3/s	CH_4 normalised %	VAM l/s maximum	VAM l/s minimum
c	61.5	60.5	0.12	73.8	72.6
d	87.0	85.0	0.11	95.7	93.5
Total			VAM returns	169.5	166.1

Table 6.33 Measured range of possible VAM make from the sealed LW7 panel

Intake VAM maximum l/s	Intake VAM minimum l/s	VAM make maximum l/s	VAM make median l/s	VAM make minimum l/s
1.2	1.1	168.4	166.7	164.9

This panel has only recently been sealed, and so its CH_4 concentration is relatively low – it was measured at just 14% through an out-bye tail-gate seal and was also measured at a low 20% on the main-gate side. What this means is that most of the leakage gas is not CH_4, and so is not contributing to VAM at the present time, but this will grow over time and the VAM make of this panel may well then be several times greater. So even though the make is not very high now (Figure 6.24), it is worthwhile to try to reduce the gas leakage which presently contains 166.7 l/s of VAM.

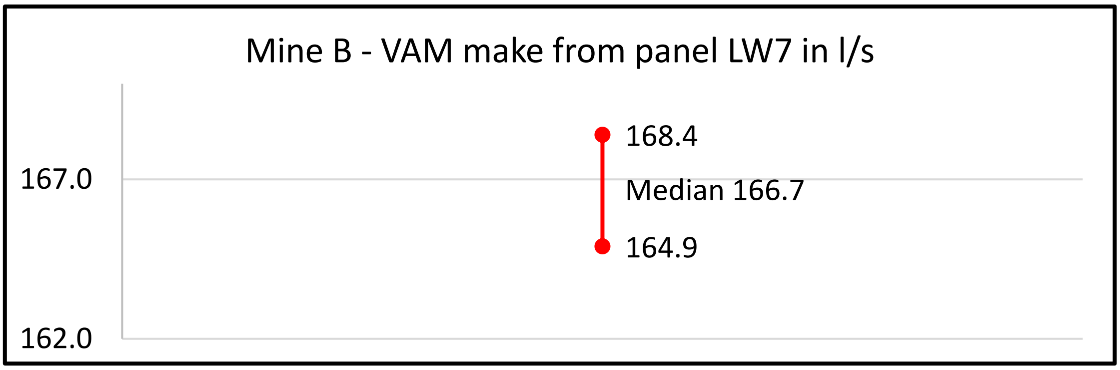


Figure 6.24 The measured median VAM make from the sealed panel LW7

The general body tube bundle measurements from tube 11 in the tail-gate (at point d) and tube 9 (at point c in Figure 6.22) in the main-gate are an average of 120 readings and 85 readings respectively, and therefore would be representative of the average VAM make for the sealed panel LW7 over time. Typical main-gate general body return CH_4 measurements from tube 9 are graphed in Figure 6.25.

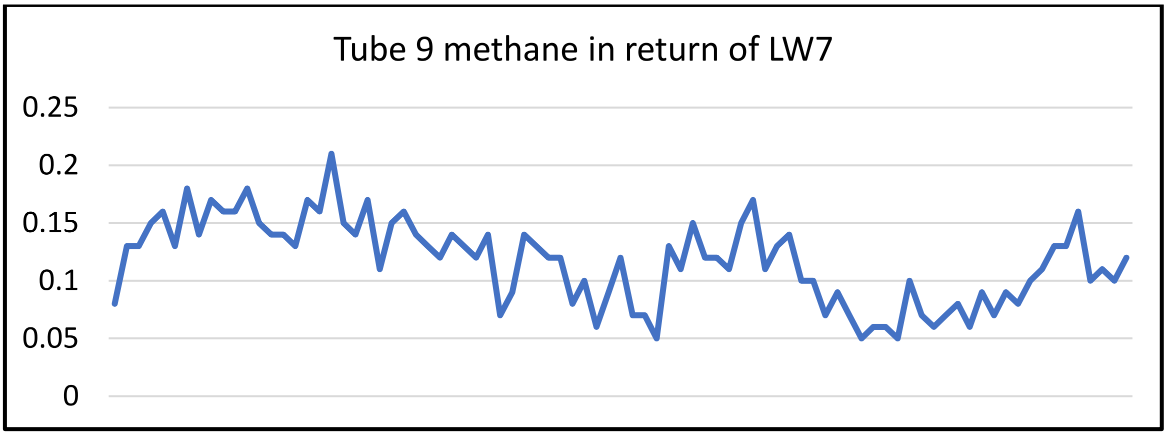


Figure 6.25 Tube 9 CH_4 from LW7 return in MG07

6.10.3 Model the initial measured panel VAM make on Ventsim

Here Ventsim has been used to show the route that the ~166.7 l/s of VAM gas which is now known to be the make of this sealed panel, takes through the mine airways (Figure 6.26).

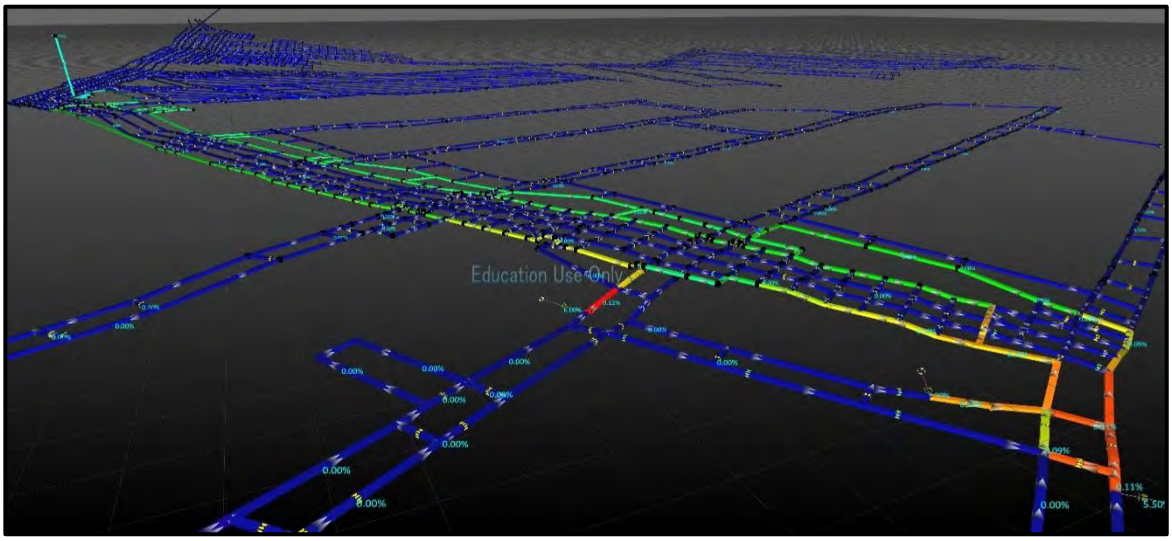


Figure 6.26 Route the LW7 VAM gas takes through the mine

The LW7 VAM leaves MG7 at 0.12% and continues down F hdg, mains until traversing overcasts to report to B hdg mains. and to shaft 1, where it combines with the TG7 VAM and exits the mine at 0.04% concentration. On the tail-gate side, the LW7 chute road picks up leakage from four LW7 out-bye seals, and leaves the area with 0.11% VAM then splits to return along E and B hdg, mains. The LW7 tail-gate roadway is still being ventilated, and after its airflow partly combines with the chute road, it leaves the area with 0.11% VAM, traverses the end of the mains, and returns along the chute roads of abandoned panel workings to shaft 1.

6.10.3.1 Discussion about LW7 chute roadway

Assumed here, is that access is required to all sides of this panel, for possible future workings – and so no consideration is given to sealing off this panel's tail-gate and back road. Of particular note, is that the majority of the in-bye end of this panel is already well pressure balanced, due to both the main-gate and the tail-gate being fed by a split from the same supply source; and neither gate road is regulated anywhere. However, something can be done at the out-bye end with the ventilated chute road, which takes all the leakage from the four out-bye seals, all of which generally breathe out strongly. This chute road is ventilated directly with fresh air from the mains, but it has some regulation already in place on the intake side. There is further regulation in place, in the form of butcher's flaps, after the two take-off roads (Figure 6.27). It is considered that the current airflow (33 m³/s) will be more than is required to serve this roadway, once the pressure balancing is done.

6.10.4 Works to pressure balance the out-bye end of LW7 panel

- remove the chute road butcher's flaps
- install a ~2 Ns²/m⁸ regulator in the tail-gate in B hdg out-bye of 1 c/t
- install a 0.5 Ns²/m⁸ set of butcher's flaps in the main-gate, B hdg out-bye of 1 c/t
- move the regulator in the tail-gate out-bye to out-bye of 1 c/t A hdg; set to 1 Ns²/m⁸
- remove the double doors from 1 c/t tail-gate
- install a 0.5 Ns²/m⁸ set of butcher's flaps in the main-gate, A hdg out-bye of 1 c/t
- remove the old coffin seal in-bye of 1 c/t A hdg, main-gate
- adjust the chute road flow to ~18 m³/s
- adjust the main-gate flow to ~37 m³/s
- check that the six out-bye seal pressures are close to the noted new seal pressures; if not, adjust the regulation to lower them to the recommended levels

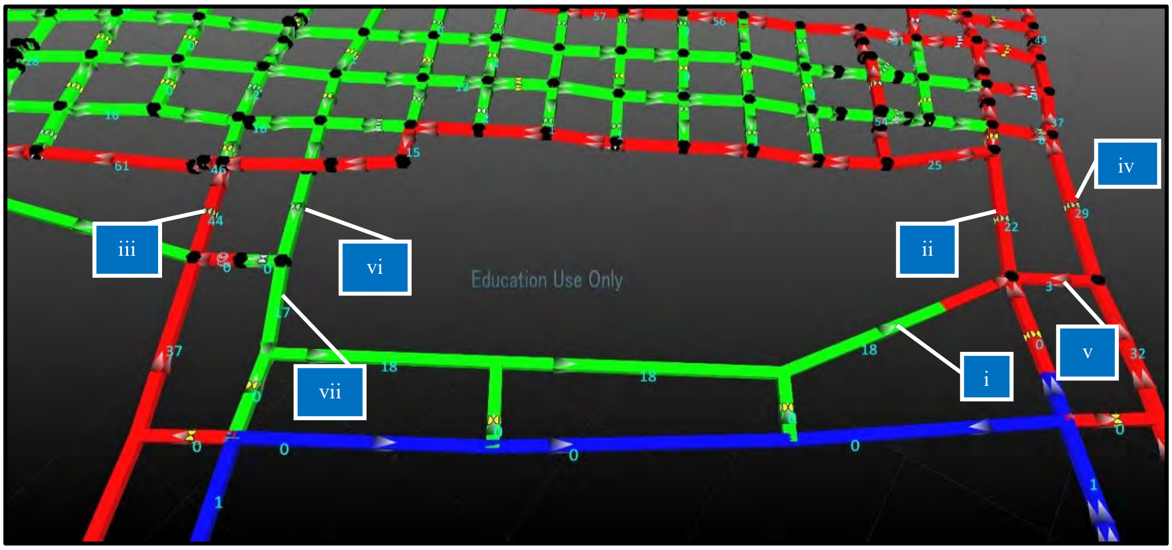


Figure 6.27 Sealed panel works to pressure balance the six out-bye seals

6.10.5 The effect of the ventilation change on seal pressures and gas leakage

The model indicates that the differential pressures across the six out-bye seals will be changed as follows;

Table 6.34 The change in pressures across the six out-bye seals

Seal	Before changes Pascals	After changes Pascals
Main-gate 2 c/t	+34	+28
Main-gate A hdg	+288	+24
Take-off road 2	+292	+26
Take-off road 1	+297	+27
Tail-gate B hdg	+307	+29
Tail-gate 2 c/t	+24	+26

6.10.5.1 Calculating the residual gas leakage into the take-off road

To calculate residual gas leakage across the seals, the formulae to be used is;

$$Q = \sqrt{P}/R$$

Because the residual pressure across the LW7 out-bye MG and TG seals is so low and similar, it will be assumed that their leakage remains unchanged, and it is the same situation for all the other LW7 in-bye seals. However, the four seals which leak into the take-off roadway will now have considerably less leakage across them; their residual leakage is calculated here. The mine figure for their seal resistance of 100,000 Ns^2/m^8 has been provided, however, seal differential pressures have also been provided, and together with the measured leakage, a more accurate seal resistance figure at this mine can be calculated thus;

Average of many measured differential seal pressures from around the panel over time is +220Pa. The leakage is 166.7 l/s of CH_4, which is at a concentration of 17% inside LW7. The actual gas leakage is then;

$$100/17 \times 166.7 = 980 \text{ l/s}$$

Which is an average gas leakage from each of the 28 seals of;

$$980/28 = 35 \text{ l/s (or } 0.035 \text{ m}^3\text{/s)}$$

To calculate the seal resistance, this formula is used;

$$R = P/Q^2 \qquad (31)$$

$$R = 220/0.035^2$$

$$R = 180{,}000 \text{ Ns}^2/\text{m}^8$$

This will be taken to be a more accurate representative seal resistance from this panel.

Table 6.35 The calculated residual leakage in across the four take-off roadway seals

MG A hdg	T/Off road 2	T/Off road 1	TG B hdg
$\sqrt{\left(\frac{24}{180000}\right)}$	$\sqrt{\left(\frac{26}{180000}\right)}$	$\sqrt{\left(\frac{27}{180000}\right)}$	$\sqrt{\left(\frac{29}{180000}\right)}$
11.0 l/s	12.0 l/s	12.0 l/s	13.0 l/s

The total gas leakage is therefore 48 l/s and the average CH_4 concentration in the out-bye end of the panel is 17%. This makes the VAM make from these four out-bye seals into the take-off roadway now just 8.2 l/s. There are 24 other seals in the panel; it is considered that these seals will not leak more than these out-bye four, and so these are taken to be representative of the worst-case leakage scenario. This being the case;

Leakage of four take-off roadway seals = 8.2 l/s
Leakage of other 24 in-bye seals is six times this = 49.2 l/s
Total residual VAM leakage is then = 57.4 l/s

VAM mitigation is initial make minus residual make; 166.7 – 57.4 = 109.3 l/s

6.10.6 Mitigation available by balancing out-bye end of panel LW7

Average VAM gas make LW7 before pressure balancing = 166.7 l/s
Average VAM gas make LW7 after pressure balancing = 57.4 l/s
Expected VAM mitigation from pressure balancing LW7 = 109.3 l/s

This mitigation quantity, when projected over a subsequent 12-month period has a CO_2 -e equivalent saving of;

0.641 gm/litre x 90.4 = 70.06 gm/s
31,550,000sec x 57.95 = 2,210 t/CH_4/yr
2,210 x 25 GWP = 5.525×10^4 t/CO_2-e / year

The model shows a residual VAM of 34% of the original flow, which works out to 0.06% of the changed return flows in the main-gate. tail-gate and the take-off road returns.

6.10.7 Cost of works calculation for panel LW7 pressure balancing

Table 6.36 Costs compared; trial balancing vs the LW7 chute roads balancing

Cost item	Trial balancing cost A$	Mine B balancing LW7 A$
Deputy and VO's time	5,000	8,000
Risk assessment	-	10,000
Mineworkers time 62hrs	-	12,000
Materials for works	-	10,000
Ventilation changes	2,000	5,000
Monitoring costs	-	5,000
Totals	7,000	50,000

6.10.8 Comparison with the 12-month trial results

Table 6.37 VAM comparison between the trial pressure balancing and LW7 balancing

	VAM abated l/s	VAM abated gm/s	t/CH_4 /y	10^4 t/ CO_2-e/y	A$ t/CO_2-e/y
Trial balancing	31.8	20.38	643	1.61	0.43
Mine B LW7	109.3	70.06	2,210	5.52	0.91

As can be seen from this comparison, much more VAM mitigation is available from LW7 than the NSW trial, but the cost per tonne is somewhat higher.

6.10.9 Overview of the safety gains by pressure balancing LW7

Pressure balancing LW7 brings with it several possible safety gains, including;

- A lower risk of a spontaneous combustion event in the panel
- A lower risk of developing a large volume of explosive gases
- Better machinery access to the returns during diurnal lows
- Less likelihood of a seal collapse due to there being less pressure on the seals
- Lower monitoring requirement due to the greater likelihood of an inert atmosphere
- Lower ventilation flow requirement to panel
- Less fugitive GHG emissions in the form of VAM

6.11 Results; the transferability of the two best mitigation measures

6.11.1 Transferring this mitigation method to other collieries

The overall results of the feasibility of transference of these two mitigation measures to different collieries, mining other seams with different gas makes, very different mine layouts and in different stages of development. The results of the modelling from the two mines, comparing available VAM reduction in CO_2-e and mitigation costs per tonne are compared in Table 6.38. All figures relate to the subsequent 12 months after the works. The transferability of these two measures to other collieries within Australia is shown to be proven. The costs are slightly higher overall, at an average of A$1.62/t/$CO_2$-e/ for the subsequent year (Table 6.39), as compared to the A$1.08 for the subsequent year during the NSW trial. In fairness, this could be due to the estimate of costs and/or the mitigation total being too conservative.

Table 6.38 Mitigation vs costs available in CO_2-e for each of the four scenarios

Place of VAM mitigation works	T/CO_2-e available	Cost/t/yr A$	Cost/t/3yr A$
Mine A seal-up LWC/E t-off road	58,380	2.72	0.91
Mine A pressure balance LWF	65,870	0.38	0.13
Mine B seal-up LW3-6 chute road	40,900	3.00	1.00
Mine B pressure balance LW7	55,250	0.91	0.31
Total t & cost per t over 1 yr & 3yr	220,400	1.62	0.55

Table 6.39 Comparison between the NSW trial and the two-measure modelled works

Place of mitigation	Tonnes of CO_2-e Available	Ave cost/t/CO_2-e in A$
NSW trial works	95,398	1.08
Two measure works Mine A	124,255	1.48
Two measure works Mine B	96,175	1.80

The direct comparison shows a surprising similarity in the amount of mitigation that is available from each of the three mines. The costs are higher in the modelled works, but not significantly so compared to mitigation costs in other areas of the economy.

6.11.1.1 All calculations are a 'snapshot' of emissions & costs over time

Although every effort has been made here to accurately reflect the likely mitigation savings which should be available at these, and by extension other collieries, it needs to be borne in mind that all these calculations are based on what amounts to a 'snapshot' of colliery emissions. Actual cost of the various works could also vary due to operational conditions from the stated estimates, so altering the final mitigation cost per averted unit of greenhouse gas emissions.

7 Chapter 7: Safety gains from the mitigation measures

(Secondary research question ii)

"What are the likely safety benefits to a colliery of implementing these mitigation measures?"

7.1 Why safety gains are to be expected

These two mitigation measures are part of an overall method, the most notable safety gains of which is to lower the percentage of methane gas in the mine returns. As a direct consequence of these reduction works, more methane is retained in goaf areas and in coal seams; and less air enters into sealed areas. These changes will be immediately recognised by those knowledgeable about coal mine ventilation, to be beneficial in terms of mine safety, both in terms of allowing better machinery and man-access to returns, and in generally lower levels of gas concentrations during barometric falls. What remains to be done here is simply to quantify these safety gains by identifying the likely type of safety improvements in each of the four modelled scenarios, and then quantifying these in a suitable risk matrix.

In the matrix, the changes will take the form of new controls, and will then be assigned a new risk rating in relation to the potential harm to people (P), the environment (E), asset damage (A) and impact on reputation (R). The risk matrix used is a coal mine specific matrix, commonly used in collieries; each likelihood/consequence rating is assigned a number to enable easy comparisons, the higher the number, the less the inherent risk. The major ventilation-related risks in any underground coal mine are; explosion, fire and exposure to an irrespirable atmosphere All of these are very relevant when sealed areas of the mine are involved in mitigation works, as they are in all cases here

7.1.1 Mine A the seal-up of LWC/E take-off road

Sealing the LWC/E take-off roadways, brings several possible safety gains, including;

- More barriers separating the working areas from any possible fire, explosion or spontaneous combustion incidents in the LWC, LWD and LWE goafs
- Less likelihood of a seal collapse due to there being lower numbers of exposed seals
- Less fugitive GHG emissions in the form of VAM
- Reduced need for seal inspections, due to there being 7 exposed seals instead of 15
- Reduced roadwork maintenance due to there being less roadways
- Less roadway inspections needed due to there being less roadways

- Lower need for the supply and maintenance of services
- Better machinery access to the returns during diurnal lows
- Lower monitoring requirement due to there being less roadways

7.1.2 Mine A the pressure balancing of LWF

Pressure balancing LWF brings with it several possible safety gains, including;

- A lower risk of developing a large volume of explosive gases
- A lower risk of a spontaneous combustion event in the panel
- Less fugitive GHG emissions in the form of VAM
- Better machinery access to the returns during diurnal lows
- Less likelihood of a seal collapse due to there being less pressure on the seals
- Lower monitoring requirement due to the greater likelihood of an inert atmosphere

7.1.3 Mine B the seal-up of LW3-6 chute roads

Sealing the LW3-6 chute roads brings several possible safety gains, including;

- More barriers separating the working areas from any possible fire, explosion or spontaneous combustion incidents in the LW3, LW4, LW5 and LW6 goafs
- Better machinery access to the returns during diurnal lows
- Less fugitive GHG emissions in the form of VAM
- Reduced roadway maintenance due to there being less roadways
- Less roadway inspections needed due to there being less roadways
- Lower need for services supply and maintenance due to there being less roadways

7.1.4 Mine B the pressure balancing of LW7

Pressure balancing LW7 brings with it several possible safety gains, including;

- A lower risk of developing a large volume of explosive gases
- A lower risk of a spontaneous combustion event in the panel
- Better machinery access to the returns during diurnal lows
- Less fugitive GHG emissions in the form of VAM
- Less likelihood of a seal collapse due to there being less pressure on the seals
- Lower monitoring requirement due to the greater likelihood of an inert atmosphere
- Lower ventilation flow requirement to panel, freeing up air for other use

RISK MATRIX

Loss Type	Hazard Effect / Consequence 1 Insignificant	2 Minor	3 Moderate	4 Major	5 Catastrophic
(P) Harm to People	Slight injury or health effects – first aid/ minor medical treatment level	Minor injury or health effects – restricted work minor lost workday case	Serious injury – major lost workday case /permanent disability	Single fatality, permanent total disabilities.	Multiple fatalities
(E) Environmental Impact	Environmental nuisance – unreasonable interference with and environmental value or contamination or pollution with a cost less than $1,000	Minor environmental harm – not trivial or negligible, potential health risks for community or pollution with costs between $1,000 & $5,000	Serious environmental harm – high local impact to and area(s) of local conservation value, with costs between $5k and $50k	Major environmental harm – high impact in district or impacts to an area of regional conservation significance, with costs between $50k & $500k	Extreme environmental harm – irreversible harm to environmental values of extreme and widespread areas, with costs greater than $500k
(A) Asset Damage & Other Consequential Losses	Slight damage <$0.1M or < 1 shift disruption to operation	Minor damage $0.1M to$1.0M. or 1 Shift – 1 day disruption to operation	Local damage $1.0M to$5.0M. 1day to 1week - disruption to operation	Major damage $5.0M to$30.0M. 1week – 1 month -Partial loss of operation	Extreme damage > $30.0M. > 1 month - Substantial or total loss of operation
(R) Impact on Reputation	Slight impact – public awareness may exist	Limited impact – some local public concern	Considerable impact – regional public concern	National impact – national public concern	international public attention

Likelihood	Likelihood Examples	Risk Rating				
A (Almost certain)	Likely the unwanted event could occur several times a year here	15 (M)	10 (H)	6 (H)	2 (Ex)	1 (Ex)
B (Likely)	Likely that the event could occur several times per year in the Australian mining industry	19 (M)	14 (M)	9 (H)	4 (Ex)	3 (Ex)
C (Possible)	The unwanted event could have occurred in Australian mining industry at some time in the past 10 years	22 (L)	18 (M)	13 (H)	8 (H)	5 (Ex)
D (Unlikely)	The unwanted event has happened in the Australian mining industry at some time; or could happen in 50 years	24 (L)	21 (L)	17 (M)	12 (H)	7 (H)
E (Rare)	The unwanted event has never been known to occur in the Australian mining industry; or is highly unlikely	25 (L)	23 (L)	20 (M)	16 (M)	11 (H)

Risk Rating	Risk Level	Guidelines for Risk Control Barriers
1 to 5	(E) – Extreme	Immediate intervention requied from Senior Management, do not proceed with activity. -
6 to 13	(H) – High	Eliminate or reduce risk by introduction of controls, do not proceed until reviewed by Senior Management -
14 to 20	(M) – Medium	Corrective action to be determined, do not proceed without authorisation from Shift Coordinator -
21 to 25	(L) – Low	Safe to continue activity once hazards minimised -

Unwanted Event - Primary Branch Hazard Assessed	Direct Causes	Inherent / Existing Controls	Loss Type	Consequence	Likelihood	Risk Rank	Risk Level	Additional Controls	Residual Rank	Residual Risk Level
MINE A										
Mine A Seal-up of LWC/E Roadways; Explosion / Fire. Spontaneous combustion or explosive atmosphere develops in goaf	Direct Causes: Ingress of air allows spontaneous combustion or an explosive atmosphere to develop	Atmosphere Management Plan & Standards Ventilation Control Device (VCD) construction standards Tube Bundle System & Real Time Gas Monitoring, Gas bag sampling regime & Gas Chromatograph Gas monitoring history & interpretation Gas alarms & TARPS Mine Inspection System Depth of cover greater than 50m Surface Land Management Plan - inspect & rehabilitate cracks Implementation of inertisation - reticulation into LW7/108 T/off roads Ventilation modeling Ignition sources identified and removed during seal-up Inertisation reduces chances and/or size of explosive atmosphere in goaf Explosions suppression management system Fire Fighting Management Plan	P A	4 2	C C	8 18	H	Second set of seals will further separate working areas from LWD, LW107 and LWE goafs More barriers will mean less leakage of air into sealed areas Create TARP specific to newly sealed areas Removal of electrical cabling and pipes prior to seal up	16 16 16 16	M
Mine A Seal-up of LWC/E Roadways; Seal collapse creating an explosive/irrespirable atmosphere in the returns	Direct Causes: Poorly built seal Materials used for construction below standard Accidental damage by machinery	Seal design standards Seal inspections Seal construction procedure Experienced and trained operators Quality checks on materials and use-by date checks Storage standards Ignition sources identified and removed Gas monitoring history & interpretation Gas alarms & TARPS	P	2	B	14	M	Second set of seals will further separate working areas from LWD, LW107 and LWE goafs More barriers will mean less pressure on individual seals	21 21	L

Unwanted Event - Primary Branch Hazard Assessed	Direct Causes	Inherent / Existing Controls	Loss Type	Consequence	Likelihood	Risk Rank	Risk Level	Additional Controls	Residual Rank	Residual Risk Level
MINE A										
Mine A Seal-up of LWC/E Roadways;	Direct Causes; Normal seam gas emissions from seams during mining	Atmosphere Management Plan & Standards Ventilation Control Device (VCD) construction standards Tube Bundle System & Real Time Gas Monitoring, Gas bag sampling regime & Gas Chromatograph Gas monitoring history & interpretation Gas alarms & TARPS Mine Inspection System Ventilation modeling	P	1	B	19	M	LWC/E roadways to be sealed up reducing VAM gas in returns	22	L
High CH_4 in the returns limiting machinery and personnel access	Lack of CH_4 mitigation efforts		R	2	B	14		Seal-up LWC/E roadways to lower GHG emissions to the environment	22	L
Excessive CH_4 escaping into the environment adding to pollution			E	2	B	14			22	L
Mine A Seal-up of LWC/E Roadways;	Direct Causes;	Mine Inspection System Seal inspection system Roadway maintenance system Air & water service maintenance regimen	P	1	C	22	L	Seal-up LWC/E roadways	24	L
Too many seals to inspect	Unnecessary roadways		A	1	C	22				
Excessive roadway maintenance	Unnecessary roadways									
Too many roadways to inspect	Unnecessary roadways									
Services not needed	Unnecessary roadways									

Unwanted Event - Primary Branch Hazard Assessed	Direct Causes	Inherent / Existing Controls	Loss Type	Consequence	Likelihood	Risk Rank	Risk Level	Additional Controls	Residual Rank	Residual Risk Level
		MINE A								
Mine A Seal-up of LWC/E Roadways; Monitoring needed in unwanted roadways	Direct Causes: Excessive VAM gas coming from unwanted roadways	Atmosphere Management Plan & Standards Ventilation Control Device (VCD) construction standards Gas Monitoring System Mine inspection system Fire Fighting Management Plan	A	1	B	19	M	Seal-up unwanted roadways	24	L
Mine A pressure balancing of LWF; Explosion / Fire. Spontaneous combustion or explosive atmosphere develops in the LWF goaf	Direct Causes: Ingress of air to a sealed panel creates either an explosive atmosphere or a spontaneous combustion incident	Atmosphere Management Plan & Standards Ventilation Control Device (VCD) construction standards Tube Bundle System & Real Time Gas Monitoring, Gas bag sampling regime & Gas Chromatograph Gas monitoring history & interpretation Gas alarms & TARPS Mine Inspection System Depth of cover greater than 50m Surface Land Management Plan - rehabilitate cracks Implementation of inertisation – pipe reticulation in the area Ventilation modeling Ignition sources identified and removed during seal-up Inertisation reduces chances and/or size of explosive atmosphere in goaf Explosions suppression management system Fire Fighting Management Plan	P	2	C	18	M	Reduce differential pressure across LWF seals by pressure balancing the panel	21	L

Unwanted Event - Primary Branch Hazard Assessed	Direct Causes	Inherent / Existing Controls	Loss Type	Consequence	Likelihood	Risk Rank	Risk Level	Additional Controls	Residual Rank	Residual Risk Level
MINE A										
Mine A pressure balancing of LWF; High CH_4 in the returns limiting machinery and personnel access Excessive CH_4 escaping into the environment adding to pollution	Direct Causes; Normal seam gas emissions from seams during mining Lack of CH_4 mitigation efforts	Atmosphere Management Plan & Standards Ventilation Control Device (VCD) construction standards Tube Bundle System & Real Time Gas Monitoring, Gas bag sampling regime & Gas Chromatograph Gas monitoring history & interpretation Gas alarms & TARPS Mine Inspection System Ventilation modeling	P	1	B	19	M	Pressure balance the LWF panel	22	L
			R	2	B	14	M	Lower the GHG emissions to the environment	22	L
			E	2	B	14	M		22	L
Mine A pressure balancing of LWF; Seal collapse perhaps partly due to high pressure on seals Close monitoring required due to ingress of air to sealed panel LWF	Direct Causes: Poorly built seal Materials used for construction below standard Accidental damage by machinery	Seal design standards Seal inspections Seal construction procedure Experienced and trained operators Quality checks on materials and use-by date checks Storage standards Ignition sources identified and removed Gas monitoring history & interpretation Gas alarms & TARPS	P	2	B	14	M	Balance the LWF panel, so lowering the pressure on most or all its seals.	21	L
								Balance the LWF panel, so reducing air ingress to the panel and reducing monitoring attention time	21	L

Unwanted Event - Primary Branch Hazard Assessed	Direct Causes	Inherent / Existing Controls	Loss Type	Consequence	Likelihood	Risk Rank	Risk Level	Additional Controls	Residual Rank	Residual Risk Level
MINE B										
Mine B Seal-up of LW 3-6 chute roads; Explosion / Fire. Spontaneous combustion or explosive atmosphere develops in any of LW3, LW4, LW5 and LW6 goafs	Direct Causes: Ingress of air allows spontaneous combustion or an explosive atmosphere to develop	Atmosphere Management Plan & Standards Ventilation Control Device (VCD) construction standards Tube Bundle System & Real Time Gas Monitoring, Gas bag sampling regime & Gas Chromatograph Gas monitoring history & interpretation Gas alarms & TARPS Mine Inspection System Depth of cover greater than 50m Surface Land Management Plan - inspect & rehabilitate cracks Inertisation - reticulation into LW7/108 T/off roads Ventilation modeling Ignition sources identified and removed during seal-up Inertisation reduces chances and/or size of explosive atmosphere in goaf Explosions suppression management system Fire Fighting Management Plan	P A	4 2	C C	8 18	H	Second set of seals will further separate working areas from LW3, LW4, LW5 and LW6 goafs	16	M
								More barriers will mean less leakage of air into these sealed goaf areas	16	
								Seal pressure reduction works reduces leakage through seals	16	
								Removal of electrical cabling and pipes prior to chute roads being sealed up	16	
Mine B Seal-up of LW 3-6 chute roads; High CH_4 in the returns during diurnal lows limiting machinery access	Direct Causes: Normal seam gas emissions from seams during mining	Atmosphere Management Plan & Standards Ventilation Control Device (VCD) construction standards Tube Bundle System & Real Time Gas Monitoring, Gas bag sampling regime & Gas Chromatograph Gas monitoring history & interpretation Gas alarms & TARPS Mine Inspection System Ventilation modeling	P	1	B	19	M	Second set of seals will further separate working areas from LW3, LW4, LW5 and LW6 goafs	22	L
								Seal pressure reduction works reduces leakage through seals	22	L

Unwanted Event - Primary Branch Hazard Assessed	Direct Causes	Inherent / Existing Controls	Loss Type	Consequence	Likelihood	Risk Rank	Risk Level	Additional Controls	Residual Rank	Residual Risk Level
MINE B										
Excessive CH_4 escaping into the environment adding to pollution	Lack of CH_4 mitigation efforts		P R E P	1 2 2 1	B B B C	19 14 19 22	M L	LW 3-6 chute roadways sealed up reducing VAM gas reporting to atmosphere	22	L
Mine B Seal-up of LW 3-6 chute roads; Excessive roadway maintenance Too many roadways to inspect Services not needed	Direct Causes: Unnecessary roadways Unnecessary roadways Unnecessary roadways	Mine Inspection System Seal inspection system Roadway maintenance system Air & water service maintenance regimen						Seal-up LW 3-6 chute roadways	24	L

Unwanted Event - Primary Branch Hazard Assessed	Direct Causes	Inherent / Existing Controls	Loss Type	Consequence	Likelihood	Risk Rank	Risk Level	Additional Controls	Residual Rank	Residual Risk Level
MINE B										
Mine B pressure balancing of LW7; Explosion / Fire. Spontaneous combustion or explosive atmosphere develops in the LW7 goaf	Direct Causes; Ingress of air to a sealed panel creates either an explosive atmosphere or a spontaneous combustion incident	Atmosphere Management Plan & Standards Ventilation Control Device (VCD) construction standards Tube Bundle System & Real Time Gas Monitoring, Gas bag sampling regime & Gas Chromatograph Gas monitoring history & interpretation Gas alarms & TARPS Mine Inspection System Depth of cover greater than 50m Surface Land Management Plan - rehabilitate cracks Implementation of inertisation – pipe reticulation in the area Ventilation modeling Ignition sources identified and removed during seal-up Inertisation reduces chances and/or size of explosive atmosphere in goaf Explosions suppression management system Fire Fighting Management Plan	P A	2 1	C C	18 22	M	Pressure balance LW7	21	L
Mine B pressure balancing of LW7; High CH_4 in the returns limiting machinery and personnel access Excessive CH_4 escaping into the environment adding to pollution	Direct Causes; Normal seam gas emissions from seams during mining Lack of CH_4 mitigation efforts	Atmosphere Management Plan & Standards Ventilation Control Device (VCD) construction standards Tube Bundle System & Real Time Gas Monitoring, Gas bag sampling regime & Gas Chromatograph Gas monitoring history & interpretation Gas alarms & TARPS Mine Inspection System Ventilation modeling	P R E	1 2 1	B B B	19 14 19	M M M	Pressure balance the LW7 panel	24	L
								Lower the GHG emissions to the environment by pressure balancing the LW7 panel	24 24	L L

Unwanted Event - Primary Branch Hazard Assessed	Direct Causes	Inherent / Existing Controls	Loss Type	Consequence	Likelihood	Risk Rank	Risk Level	Additional Controls	Residual Rank	Residual Risk Level
MINE B										
Mine B pressure balancing of LW7; Seal collapse partly due to high pressure on seals Close monitoring required due to ingress of air to sealed panel LW7 High airflow requirement for LW7 area	Direct Causes: Poorly built seal Materials used for construction below standard Accidental damage by machinery Air ingress to LW7 sealed panel Leakage of methane from LW7 sealed panel into returns	Seal design standards Seal inspections Seal construction procedure Experienced and trained operators Quality checks on materials and use-by date checks Storage standards Ignition sources identified and removed Gas monitoring history & interpretation Gas alarms & TARPS	P	2	B	14	M	Balance the LW7 panel, so lowering the pressure on most or all its seals.	21	L
								Balance the LW7 panel, so reducing air ingress to the panel and reducing monitoring attention time Balance the LW7 panel, so reducing gas escape from the panel, so lowering airflow requirements in the area	21	L

7.2 Safety gains achieved due to mitigation works

The nature of these mitigation works measures, even though they are primarily designed to reduce VAM make, is such that they can be considered to be additional controls on risk, which will each individually *reduce* the likelihood of an unwanted and potentially very costly event in the mine. Here is where this method of VAM mitigation is fundamentally different to the method which treats the VAM upon its exit from the mine fans, such as VAMTOX and other commercial VAM treatment plants; the nature of all these plants is such that they *increase* the risk of an incident. As can be seen from the above risk assessment, all of the areas just identified as those where possible safety gains could be made, actually achieved some improvement. Hence, by its very nature, this mitigation method and all its measures individually, enhances mine safety.

7.2.1 Mine A; the seal-up of LWC/E take-off road

Nine areas were identified with respect to the seal-up of LWC/E, where safety gains might reasonably be expected to be made. As a part of this mitigation effort, more than 2.5km of unnecessary mine roadways were sealed up, and were then pressure balanced to reduce differential pressures across the six newly installed and the one existing seals. Removing this amount of ventilated roadway from the mine, obviously comes with considerable savings with regards to the provision of mine services, roadway maintenance, seal and roadway inspections and monitoring requirements. The works also resulted in a VAM reduction in the returns of 115 l/s, improving machinery access to these roadways and reducing ventilation demand. A significant benefit from the seal-up was the quantified reduction in the likelihood of a spontaneous combustion/fire/explosion event in the sealed panels LWC, D or E; and in the reduced likelihood of any such event severely affecting mine personnel.

7.2.2 Mine A; the pressure balancing of LWF

Six areas were identified with respect to the pressure balancing of LWF, where safety gains might reasonably be expected to be made. The LWF pressure balancing works were carried out at the out-bye end of the panel. The main benefits apart from the VAM savings of 130 l/s were the reduction in seal pressures, and the access improvements to the returns during diurnal lows. Reductions in the likelihood of a spontaneous combustion/fire/explosion event were also significant.

7.2.3 Mine B; the seal-up of LW3-6 chute roads

Six areas were identified with respect to the seal-up of the LW3-6 chute roads, where safety gains might reasonably be expected to be made. As noted, these works would not normally be considered for return ventilation resistance reasons, but no other candidate roadways presented themselves for seal-up at Mine B. Gains were quantified in all six assessed areas; of note is the reduction in the likelihood of occurrence of a spontaneous combustion/fire/explosion event in sealed panels LW3, LW4, LW5 and LW6, and in the reduced likelihood of any such event severely affecting mine personnel due to the extra barrier seals. Here, 1.5km of mine roadway was removed from the need for ventilation, inspections, provision of services and maintenance. VAM savings were calculated at 81 l/s

7.2.4 Mine B; the pressure balancing of LW7

Seven areas were identified with respect to the pressure balancing of LW7, where safety gains might reasonably be expected to be made. VAM make was reduced considerably, savings were 109 l/s; this also reduced the ventilation requirements along the LW7 take-off roadway. The four take-off seals had their differential pressures reduced from ~300Pa to ~30Pa, providing a worthwhile reduction in air ingress to the sealed panel, so reducing the likelihood of spontaneous combustion or an explosive atmosphere developing.

7.3 Safety aspects – a summary

In all cases, safety gains were made. This is unsurprising given that the result of the mitigation works was variously;

- to lower the CH_4 concentrations in the mine atmosphere
- to lower the pressure differentials across seals
- to reduce the number of seals requiring inspection
- to better pressure balance sealed panels
- to increase the barriers between goaf areas and working areas of the mine
- to reduce maintenance and inspection requirements
- to reduce the requirement for mine services
- to increase machinery access to the returns
- to free up some mine air for other use
- to reduce GHG emissions to the atmosphere

Safety benefits were not generally large, but nevertheless were found to be significant and widespread across all areas of risk, including people, environmental, assets and reputational. Gains in public relations/reputational aspects are also expected to flow from reducing emissions, but are difficult to quantify and so are not included here.

7.4 Generating carbon credits

(Secondary research question iii)

"What are the possible benefits with regard to the generation of carbon credits for a colliery?"

The government's direct-action plan (Regulator, 2012), arranged through the clean energy regulator, involves applications for funding under an auction system; the fact that VAM is covered, means that funding of these VAM mitigation measures should be available.

7.4 Mine A – available carbon credits

At Mine A, and if fully claimed under the direct-action auction system, at the last Australian carbon credit unit price of A$10.69, the funding available for one projected year of mitigation, would be A$1,328,000 (Table 7.1). Net benefit after costs would be A$1,144,000.

Table 7.1 Australian carbon credits available for Mine A converted to A$

Measure employed	t/CO_2-e 1 year	Mitigation funding available A$
Seal-up LWC/E take-off road	58,380	624,000
Pressure balancing LWF	65,870	704,000
Totals	124,250	1,328,000
Less cost of mitigation works		-184,000
Net benefit to Mine A		1,144,000

7.5 Mine B – available carbon credits

At Mine B, and if fully claimed under the direct-action auction system, at the last Australian carbon credit unit price of A$10.69, the funding available for one projected year of mitigation, would be A$1,028,000 (Table 7.2). Net benefit after costs would be A$855,000.

Table 7.2 Australian carbon credits available for Mine B converted to A$

Measure employed	t/CO_2-e 1 year	Mitigation funding available A$
Seal-up LW3-6 chute roads	40,900	437,000
Pressure balancing LW7	55,250	591,000
Totals	96,150	1,028,000
Less cost of mitigation works		-173,000
Net benefit to Mine B		855,000

The available tradable Australian carbon credits for both mines totals A$2,356,000 for the subsequent year alone; however, more than one year's mitigation should be claimable, since the type of mitigation method means that the savings are on-going for at least three years in total. The costs of the mitigation works are minimal compared to the credits available, so resulting in a net financial benefit to each mine of ~A$1m; this, combined with the quantified safety gains, and gains in public relations, obviously increases the incentive to mitigate.

CONCLUSION

Cutting colliery emissions cost-effectively and safely

It is clear that actions to reduce fugitive GHG emissions such as residual VAM gas from a colliery were not even considered until very recently. Residual being defined as that VAM which remains after sufficient gas drainage has taken place to reduce gas levels to below outburst potential, and down to a level where the ventilation system can keep gases to safe levels and within statutory limits. The new paradigm of a possible financial impost in the form of a carbon tax or a reputational cost in relation to residual fugitive VAM emissions means that greater consideration needs to be given to ventilation planning in relation to controlling VAM fugitive emissions both before and throughout mine production. Currently, there are no costs or restrictions on VAM gas emissions, either in Europe, the USA, or in Australia. However, cutting these emissions is encouraged, and funding for this is possible in Australia through the clean energy authority, and would be at no net cost to the mine – provided the mitigation cost is below the auction price (presently ~A$10/t CO_2-e). The difficulties in dealing with residual VAM gas, and the problems experienced in practice with large-scale VAM mitigation plants are detailed in chapter two. An interim but admittedly partial solution to this problem of residual VAM gas emissions is presented in chapters five and six. Included below, are estimates of the possible contribution that this method may make to Australia's international 2020 and 2030 emissions target commitments.

The success of the 12-month VAM mitigation trial

It has been demonstrated here that in the trial, high fugitive residual VAM emissions associated with longwall mining and the potentially higher fugitive emissions associated with multi seam or deeper seam mining can be safely and cost-effectively reduced, by using the method identified, quantified and costed in chapter five. The 12-month trial of this VAM mitigation method, includes six quantified and costed measures in an operating Hunter Valley multi seam longwall colliery. Together, these achieved a total mitigation of 95,398 t/CO_2-e in the first year at an average cost of A$1.08 per t/$CO_2$-e abated, and the potential remained for the mitigation of a further 50,000 t/CO_2-e/yr at an estimated cost of A$2-A$4 per CO_2-e tonne (R. Holmes, 2016a). This is the first time, to the author's knowledge, that this method of non-gas drainage VAM mitigation, using six separate measures, has been trialled, quantified and costed. What this method represents is a possible 'stop-gap' means of reducing the 'low-hanging fruit' residual VAM emissions by perhaps ~20%, until such time as the large-scale VAM plants have proved themselves to be ready for safe and economical wide-spread use.

Validating the transferability of the trial results

The primary research question posed in chapter one relates to transferability of the successful method used in the 12-month trial to other, similar Australian collieries. Specifically, can the two most successful measures used in the 12-month trial, namely road sealing and pressure balancing of sealed panels be used just as well in other Australian collieries? As a practical matter, these were not able to be tested in a second trial but could be modelled using actual mine data. To this end, underground visits were made in August 2016 to two large Queensland long-wall collieries, where gas, seal pressure, airflow and much other operational data over time was directly obtained.

The two best mitigation measures from the trial were then assessed in chapter six by modelling the gas, airflow and pressure data in Ventsim visual, to assess whether this mitigation method could be successfully applied across other VAM-affected longwall collieries in Australia – so in effect validating or invalidating the transferability of the method. Transferability is important, because if the method can be used widely, then a far greater portion of Australia's current ~40mt/CO_2-e of VAM fugitive emissions could potentially be targeted. And this figure represents 6.5% of Australia's total greenhouse gas emissions. The measures were shown to be just as successful in terms of mitigation quantity at these two collieries as it was during the trial, but the estimated cost of the works was somewhat higher. A direct comparison of the mitigation amounts, and costs is contained in Table 6.39.

Even though mitigation costs were estimated to be higher in the Queensland mines, all estimated mitigation costs still remain far below mitigation costs in other areas of the economy. Across areas such as the old carbon pricing mechanism, the prevailing low carbon price in Europe, wind and solar mitigation costs (Wharburton, 2014) or the Australian government's emission reduction fund's average 2016 Australian carbon credit price of A$10.69 t/$CO_2$-e abated, under its direct-action plan (Regulator, 2012). This is especially so when a more realistic time abatement period is used than just the conservative 1 year (Table 5.11). It can be seen that 3-year abatement costs for the most successful measure in the trial (measure 2) are A$0.44 t/$CO_2$-e and a 5-year period reduces costs further to A\$0.29 t/CO_2-e. Here is the great advantage of this method of GHG reduction and is where it stands out among other trialled and costed methods; that of low-cost mitigation. In terms of the colliery itself, there are other, and not insignificant benefits. These are; better machinery and personnel access to returns, increased safety due to lower methane gas levels in returns, (which has been quantified in chapter seven) and public relations benefits. Importantly, the environmental benefits, access benefits, safety benefits and public relations benefits should all be achievable at no net financial cost to the mine, if carbon credits are applied for and then sold through the government's direct-action scheme; as is detailed in chapter seven.

From the modelling results in chapter six, it is very likely that the main research question is answered in the affirmative; that is that the mitigation results and costs obtained in the NSW trial should generally be obtainable in other VAM-affected Australian collieries.

The advantages of this method

The great advantages of this mitigation method are;

- achievable immediately because it requires no new, expensive or unproven technology
- at a very low cost compared to mitigation performed in other areas of the economy
- does not compromise safety, in fact all the measures whether used individually or collectively, enhance mine safety - in particular in regard to access in the returns
- approximately ~10% of the bipartisan 2020 remaining emissions reduction target is a possibility using this method, and at least a few percent of Australia's 2030 Paris emissions target emissions reduction
- no disruption to mine production
- able to provide tradable carbon credits to the collieries or a cash benefit for mitigating if a successful application is made under the direct-action auction system
- a public relations benefit should be realised; the work needs to be promoted on the mine's web site and through public awareness opportunities such as media releases

This work has been produced in order to identify significant contributions that collieries in Australia could make to the government's 2020 and 2030 GHG emission reduction targets, in a cost-effective and safe manner. This has been achieved; it has been demonstrated that approximately 20% of a collieries' residual and fugitive VAM emissions can be directly targeted and eliminated by the use of the six specific VAM mitigation measures outlined in chapter five. It has also been demonstrated through the modelling of actual gas, pressure and airflow data obtained from two large Queensland collieries, that the method is transferable - with remarkably similar results in terms of mitigation tonnage. However, there was discovered to be a significant associated increase in mitigation costs, but this is seen to be a manageable increase since estimated mitigation costs are still far below mitigation costs across other sectors of the economy.

It is believed by the author, that several or all of these measures could be implemented in VAM-affected Australian collieries, at a modest cost, and with significant benefits in terms of both fugitive emissions reductions and better access to returns. These measures could form a VAM mitigation 'low-hanging fruit' or interim method, until such time as cost-effective, safe and reliable VAM mitigation plants have been developed for widespread use in collieries.

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